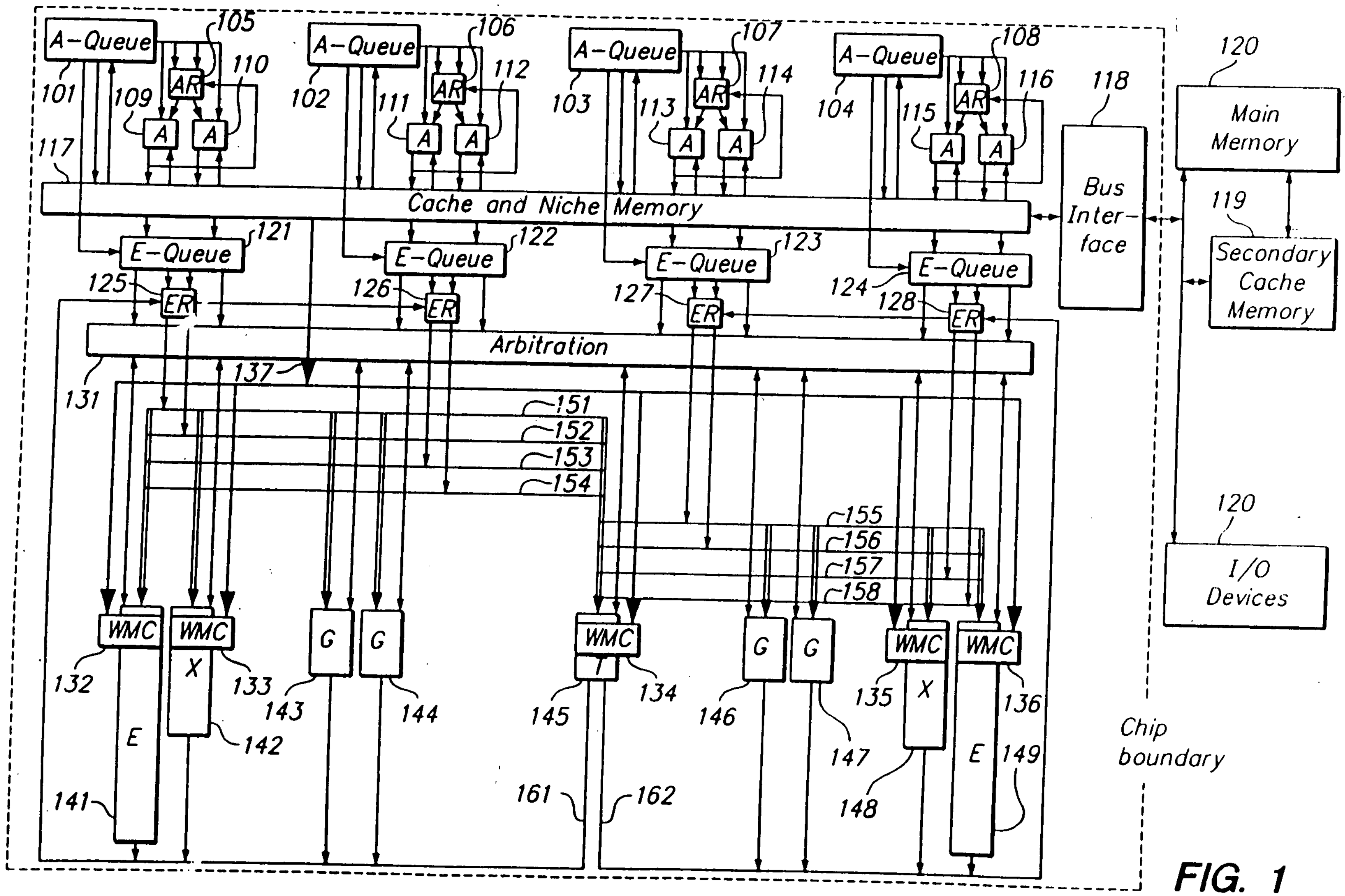

A-Queue
A-Queue
A-Queue
A-Queue
AR
A
Cache and Niche Memory
E-Queue
E-Queue
E-Queue
E-Queue
ER
Arbitration
Bus Inter-face
Main Memory
Secondary Cache Memory
I/O Devices
WMC
E
X
G
T
Chip boundary

FIG. 1

$$\square\, rd_{128} = m[rc]_{(128*64/size)} * rb_{128}$$

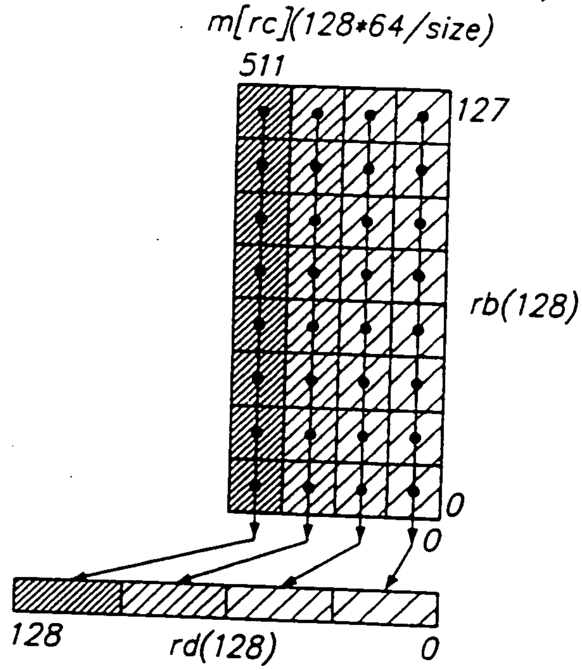


FIG. 2

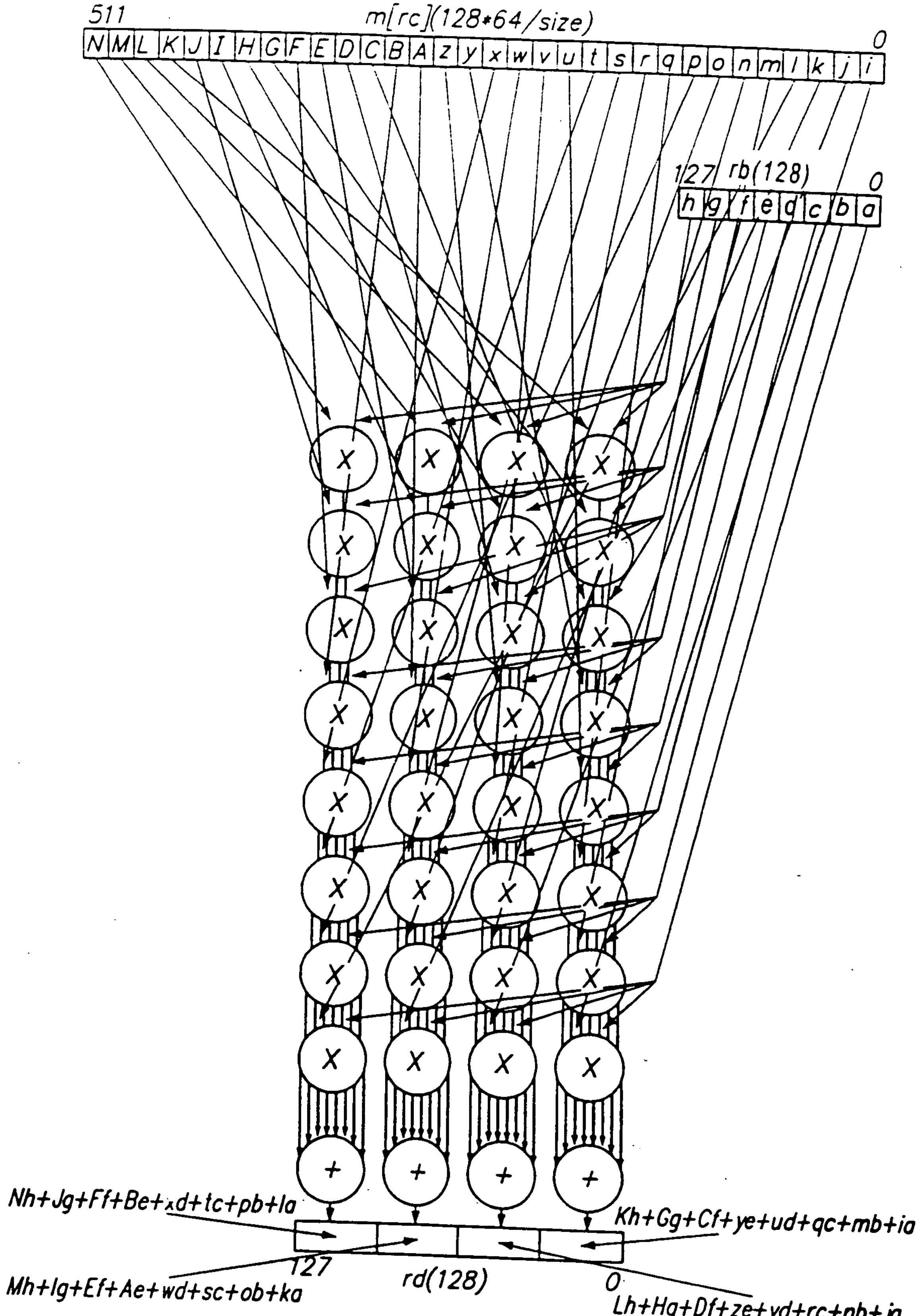
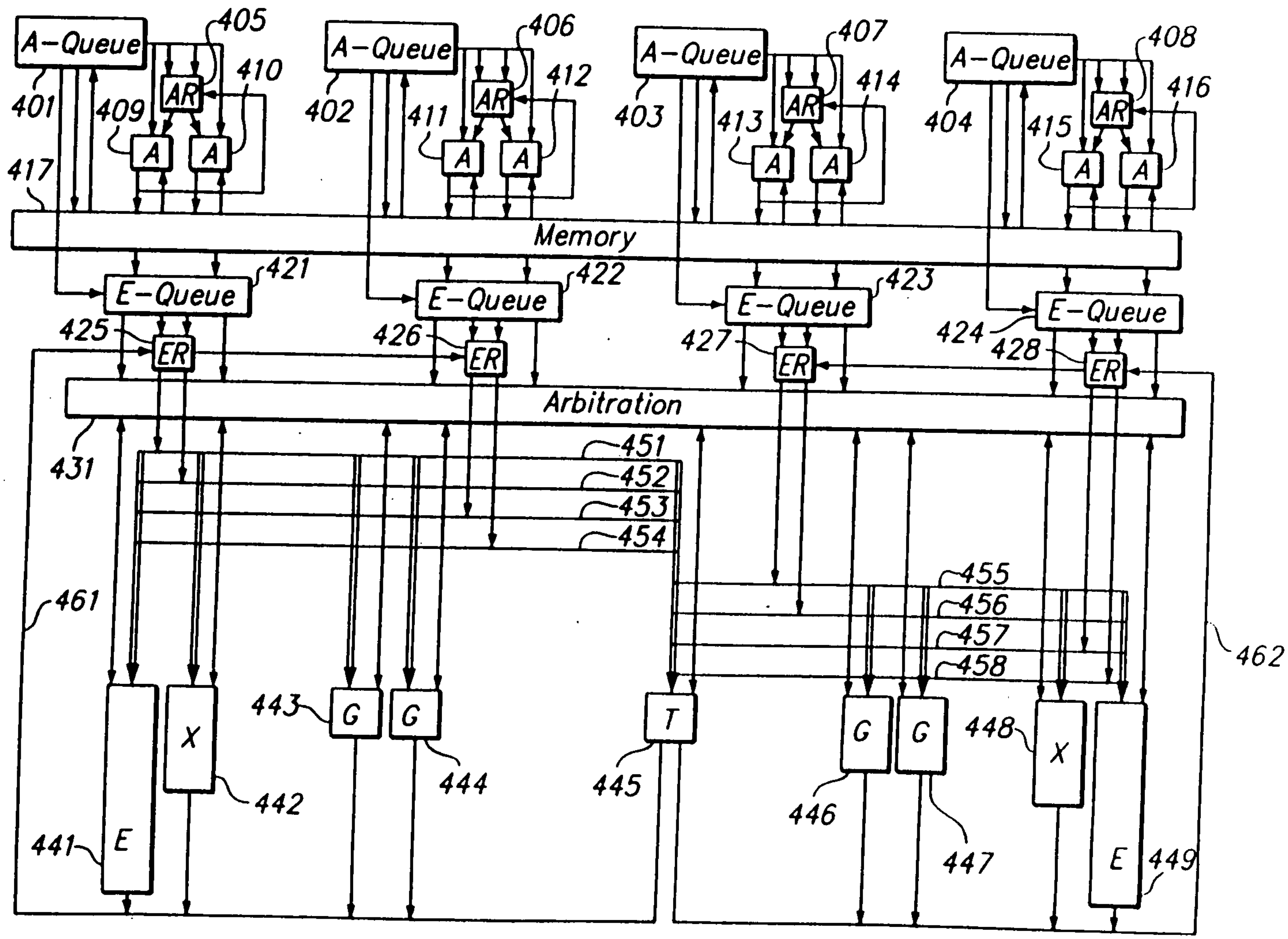

511
m[rc](128*64/size)
N M L K J I H G F E D C B A z y x w v u t s r q p o n m l k j i
0
127 rb(128) 0
h g f e d c b a
X
+
Nh+Jg+Ff+Be+xd+tc+pb+la
Kh+Gg+Cf+ye+ud+qc+mb+ia
127
rd(128)
0
Mh+Ig+Ef+Ae+wd+sc+ob+ka
Lh+Hg+Df+ze+vd+rc+nb+ja

FIG. 3



A-Queue
A-Queue
A-Queue
A-Queue
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
AR
A
Memory
E-Queue
421
422
423
424
425
426
427
428
ER
Arbitration
431
451
452
453
454
455
456
457
458
461
462
E
X
G
T
441
442
443
444
445
446
447
448
449

FIG. 4

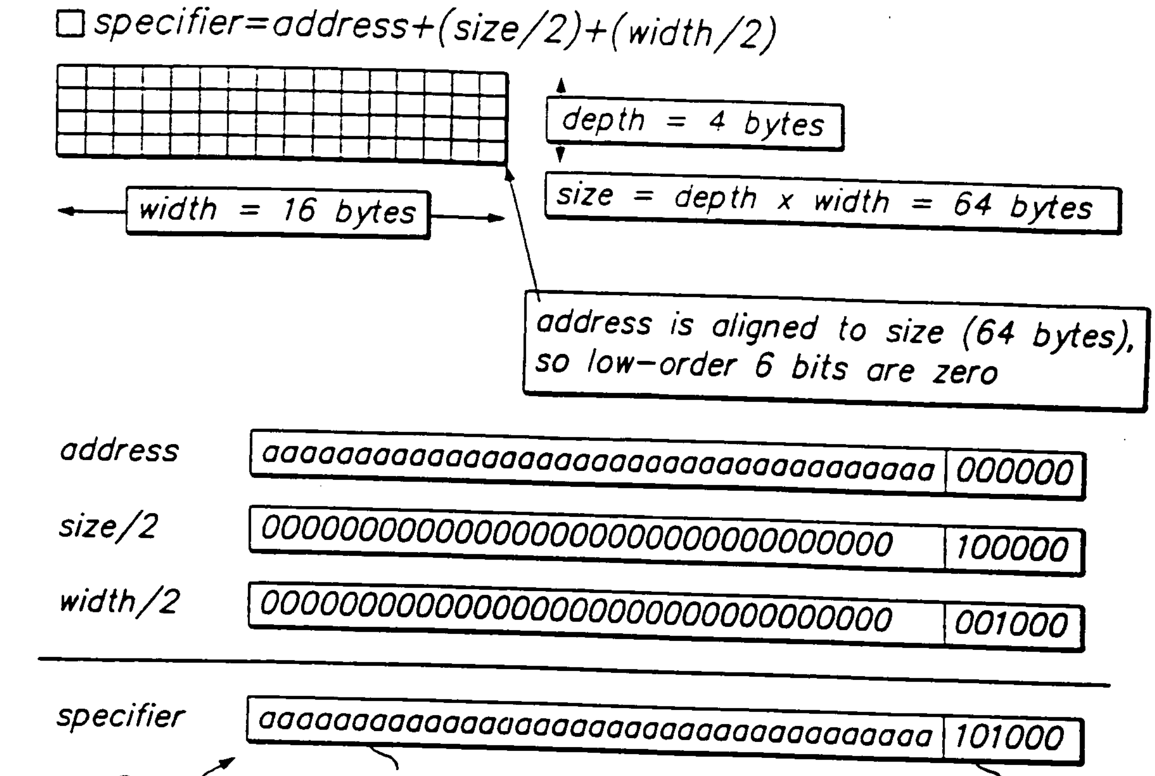

specifier=address+(size/2)+(width/2)
depth = 4 bytes
size = depth x width = 64 bytes
width = 16 bytes
address is aligned to size (64 bytes), so low-order 6 bits are zero
address aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 000000
size/2 0000000000000000000000000000000000 100000
width/2 0000000000000000000000000000000000 001000
specifier aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 101000
500
505
510

FIG. 5

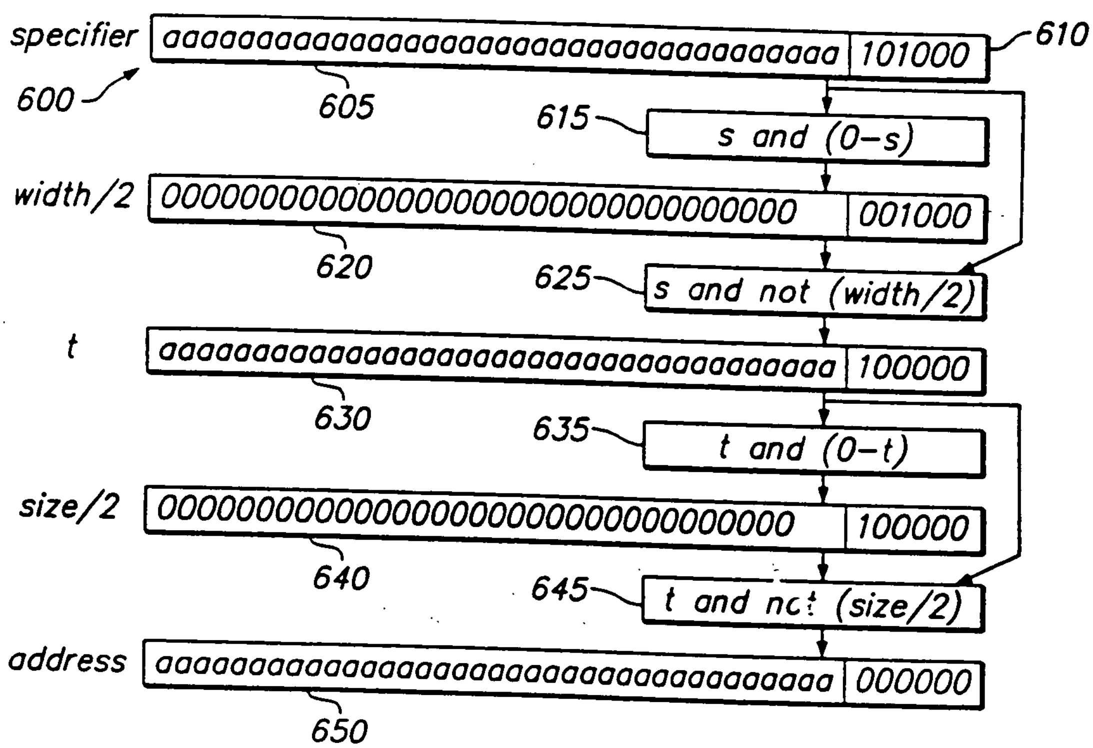

specifier aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 101000
610
600
605
615
s and (0-s)
width/2 0000000000000000000000000000000000 001000
620
625
s and not (width/2)
t aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 100000
630
635
t and (0-t)
size/2 0000000000000000000000000000000000 100000
640
645
t and not (size/2)
address aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa 000000
650

FIG. 6

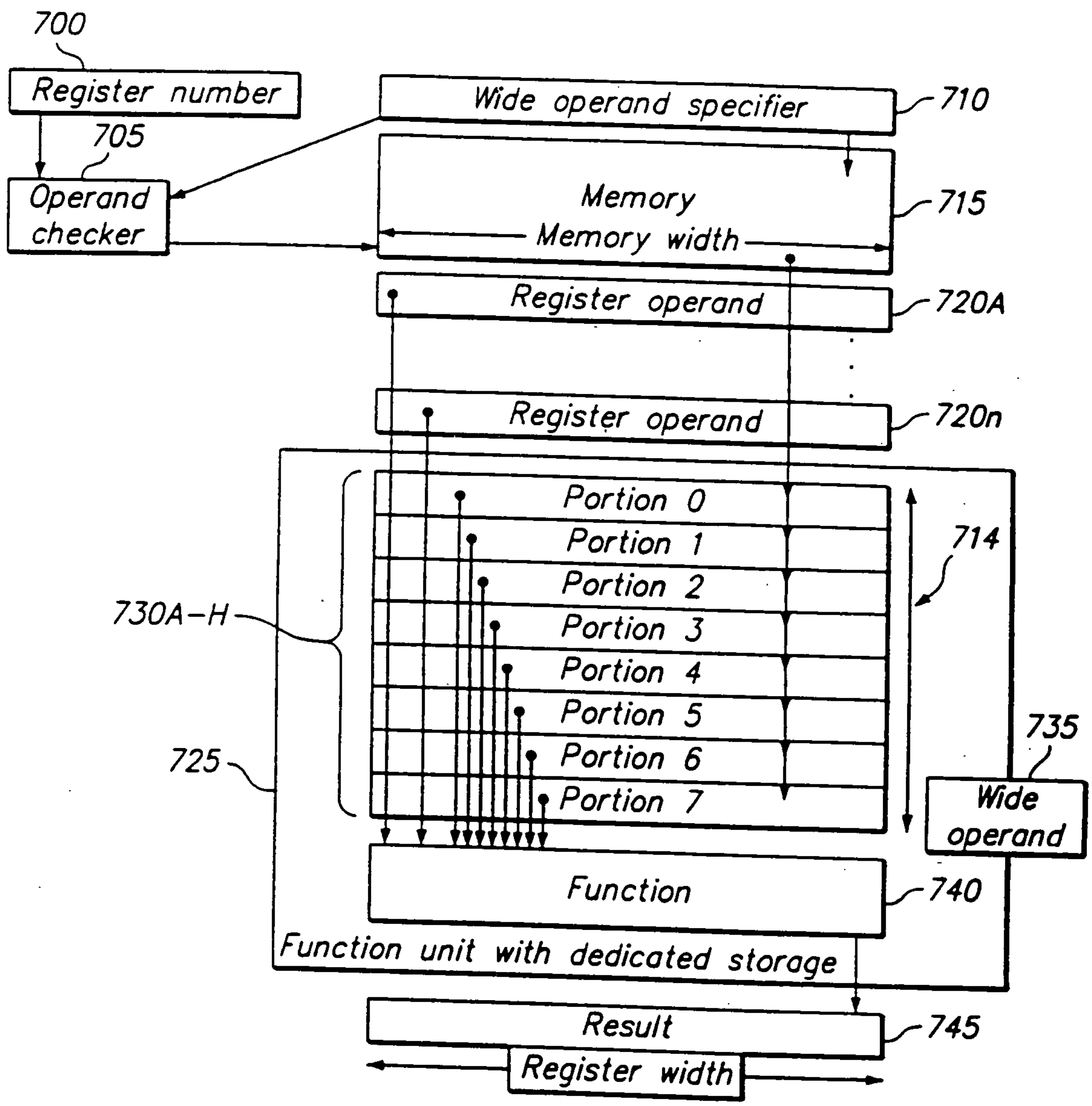
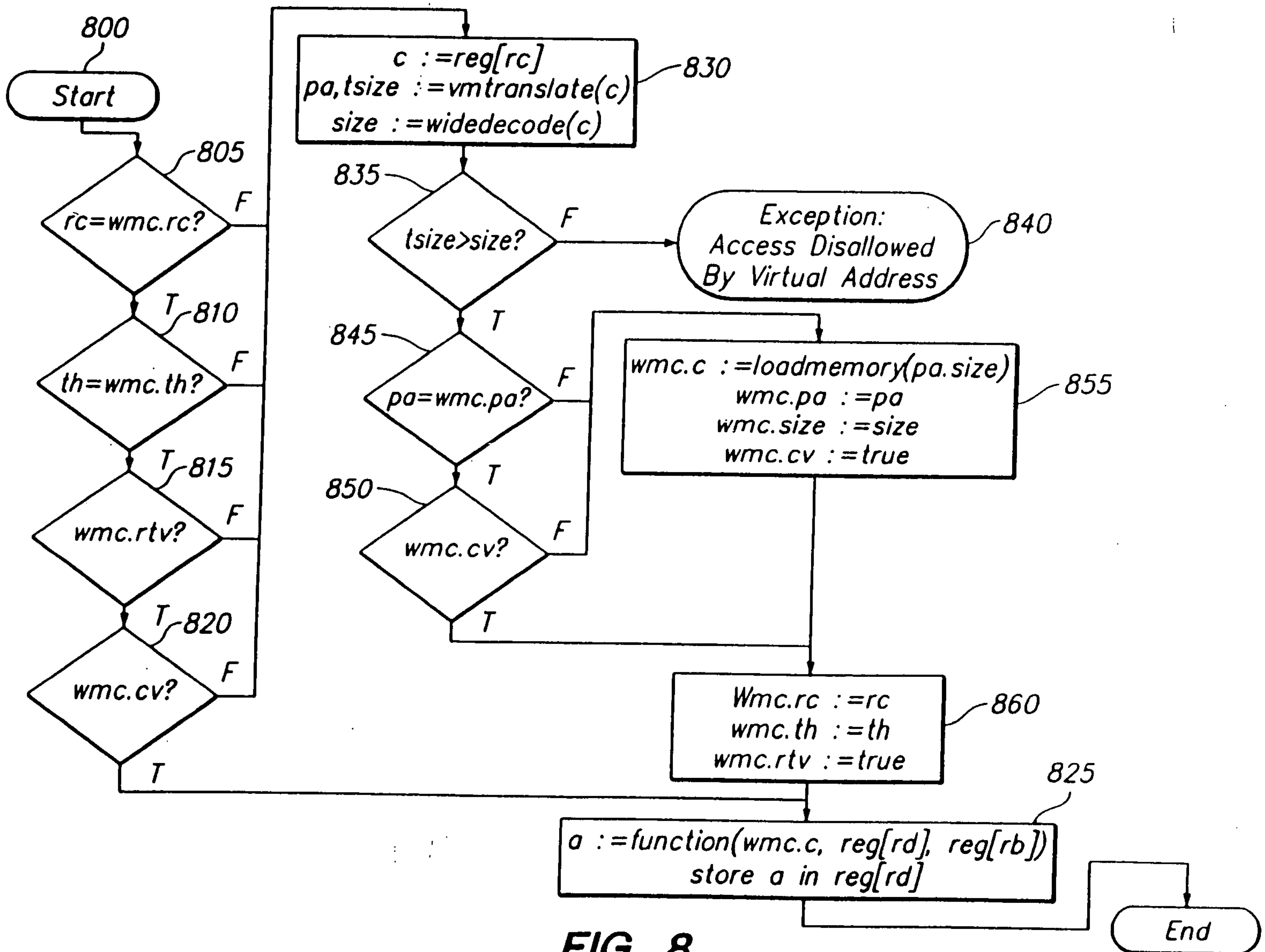

700
Register number
705
Operand checker
Wide operand specifier
710
Memory
Memory width
715
Register operand
720A
Register operand
720n
Portion 0
Portion 1
Portion 2
Portion 3
Portion 4
Portion 5
Portion 6
Portion 7
714
730A-H
725
735
Wide operand
Function
740
Function unit with dedicated storage
Result
745
Register width

FIG. 7



800
Start
805
rc=wmc.rc?
810
th=wmc.th?
815
wmc.rtv?
820
wmc.cv?
T
F
c :=reg[rc]
pa,tsize :=vmtranslate(c)
size :=widedecode(c)
830
835
tsize>size?
Exception:
Access Disallowed
By Virtual Address
840
845
pa=wmc.pa?
850
wmc.cv?
wmc.c :=loadmemory(pa.size)
wmc.pa :=pa
wmc.size :=size
wmc.cv :=true
855
Wmc.rc :=rc
wmc.th :=th
wmc.rtv :=true
860
825
a :=function(wmc.c, reg[rd], reg[rb])
store a in reg[rd]
End

FIG. 8

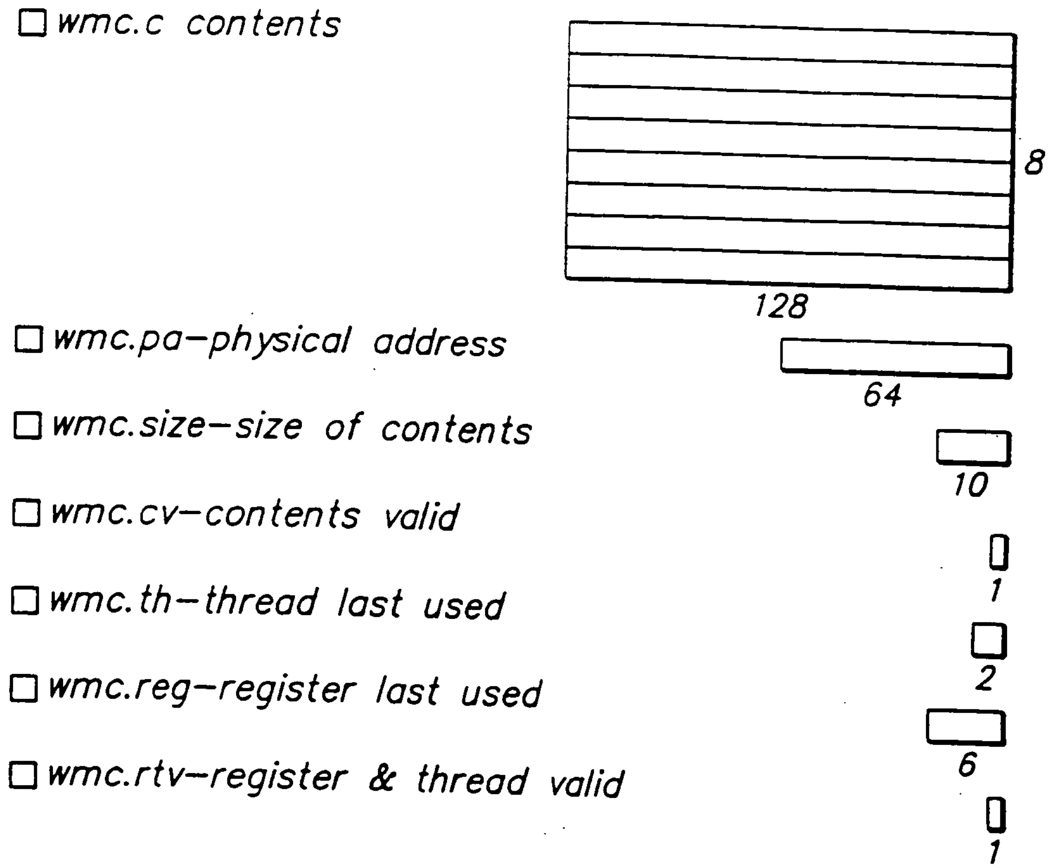
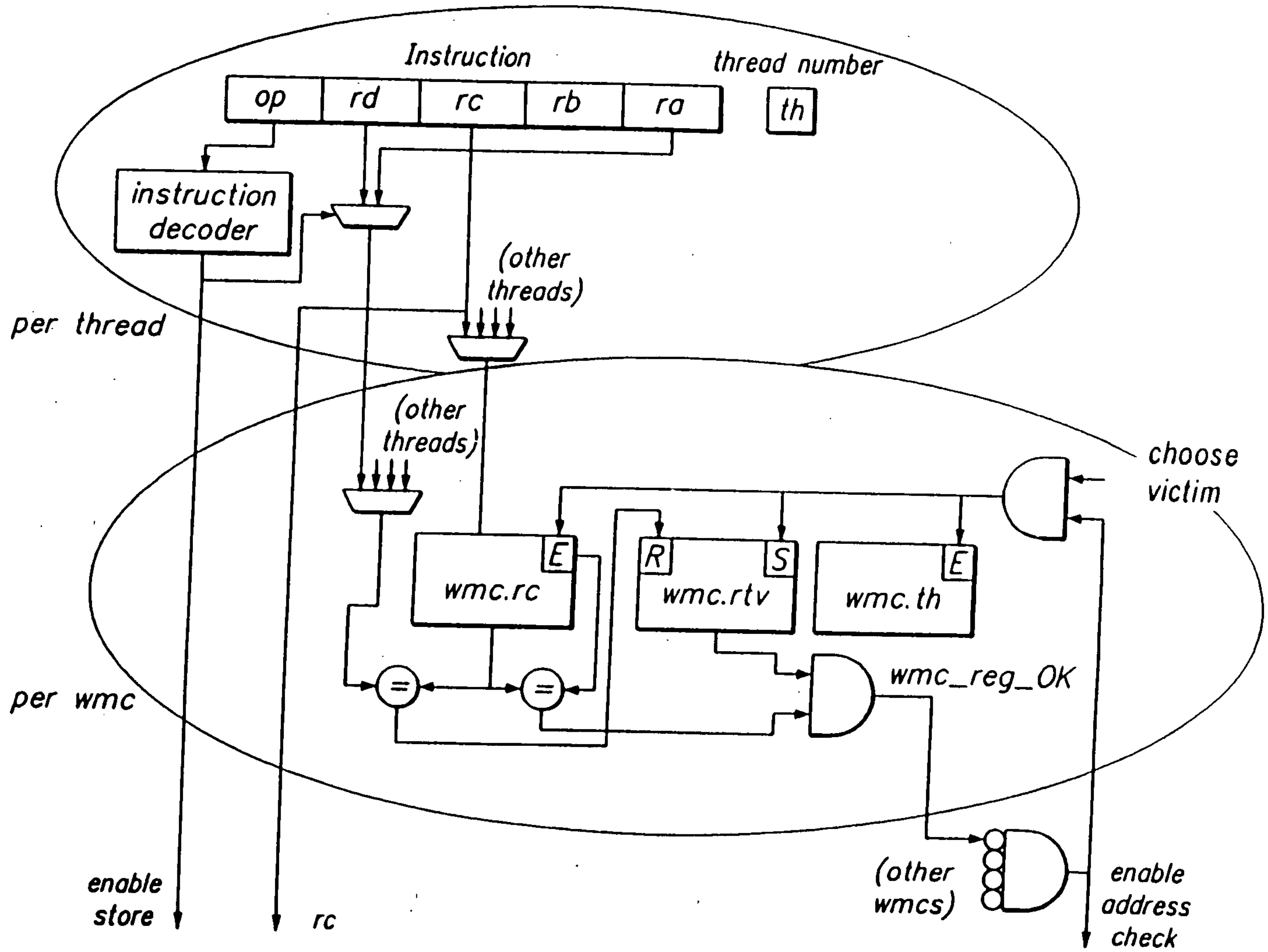

wmc.c contents
wmc.pa–physical address
wmc.size–size of contents
wmc.cv–contents valid
wmc.th–thread last used
wmc.reg–register last used
wmc.rtv–register & thread valid
8
128
64
10
1
2
6
1

FIG. 9



Instruction
op
rd
rc
rb
ra
thread number
th
instruction decoder
(other threads)
per thread
(other threads)
choose victim
E
wmc.rc
R
S
wmc.rtv
E
wmc.th
=
=
wmc_reg_OK
per wmc
(other wmcs)
enable store
rc
enable address check

FIG. 10

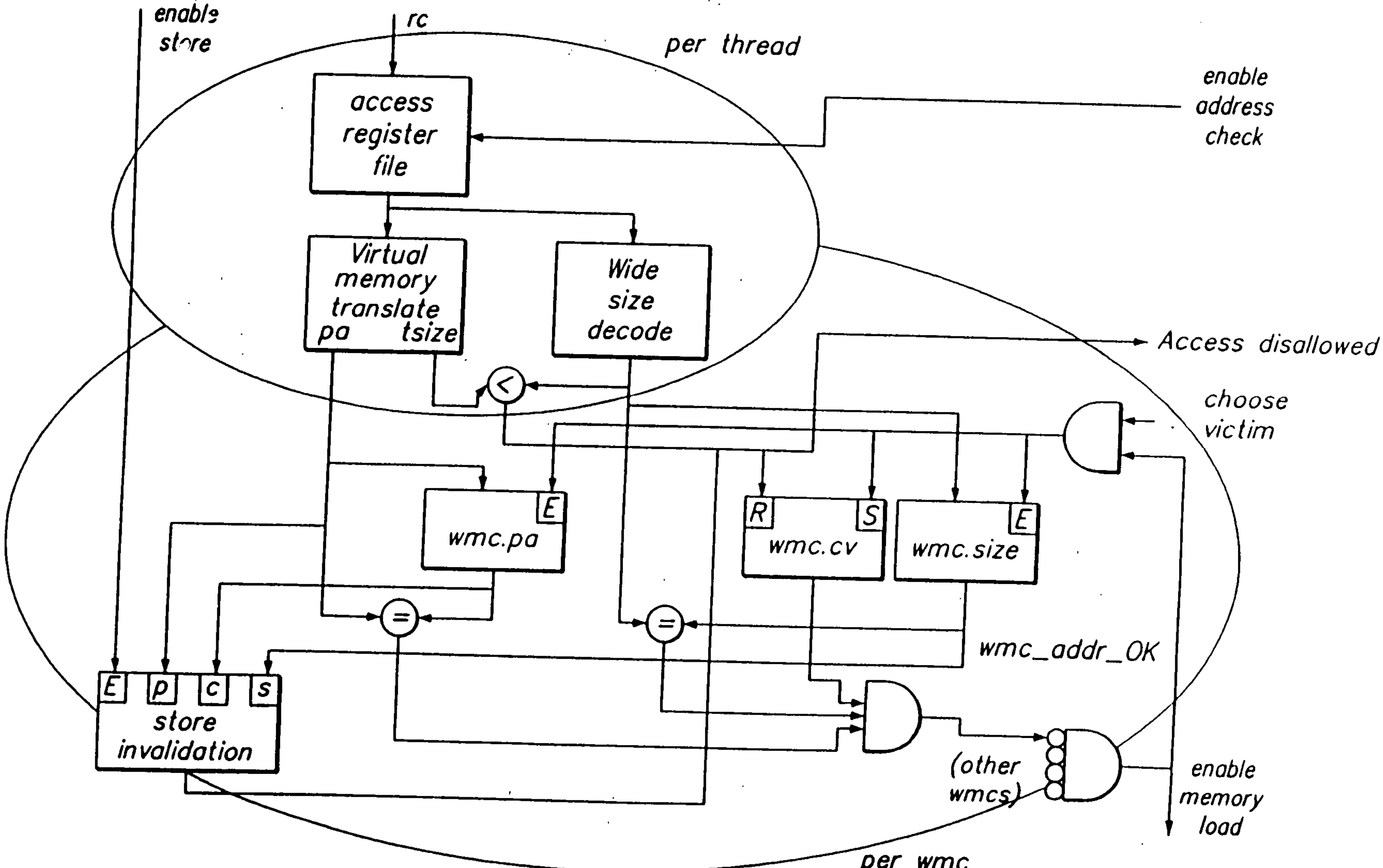

enable store
rc
per thread
access register file
enable address check
Virtual memory translate
pa
tsize
Wide size decode
Access disallowed
choose victim
wmc.pa
E
R
S
wmc.cv
wmc.size
E
wmc_addr_OK
E
p
c
s
store invalidation
(other wmcs)
enable memory load
per wmc

FIG. 11

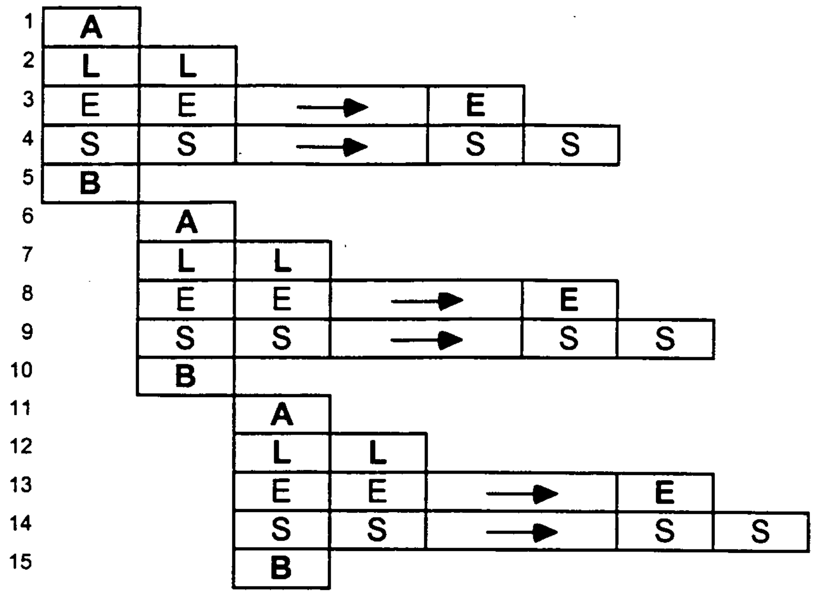

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
A
L
E
S
B

Fig. 12

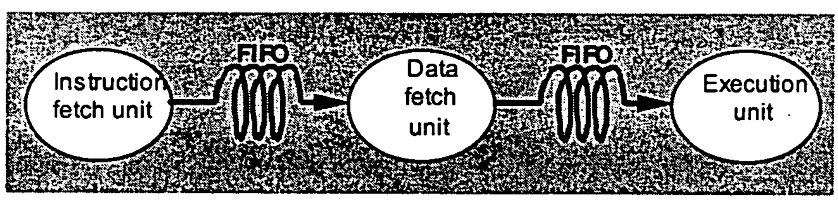
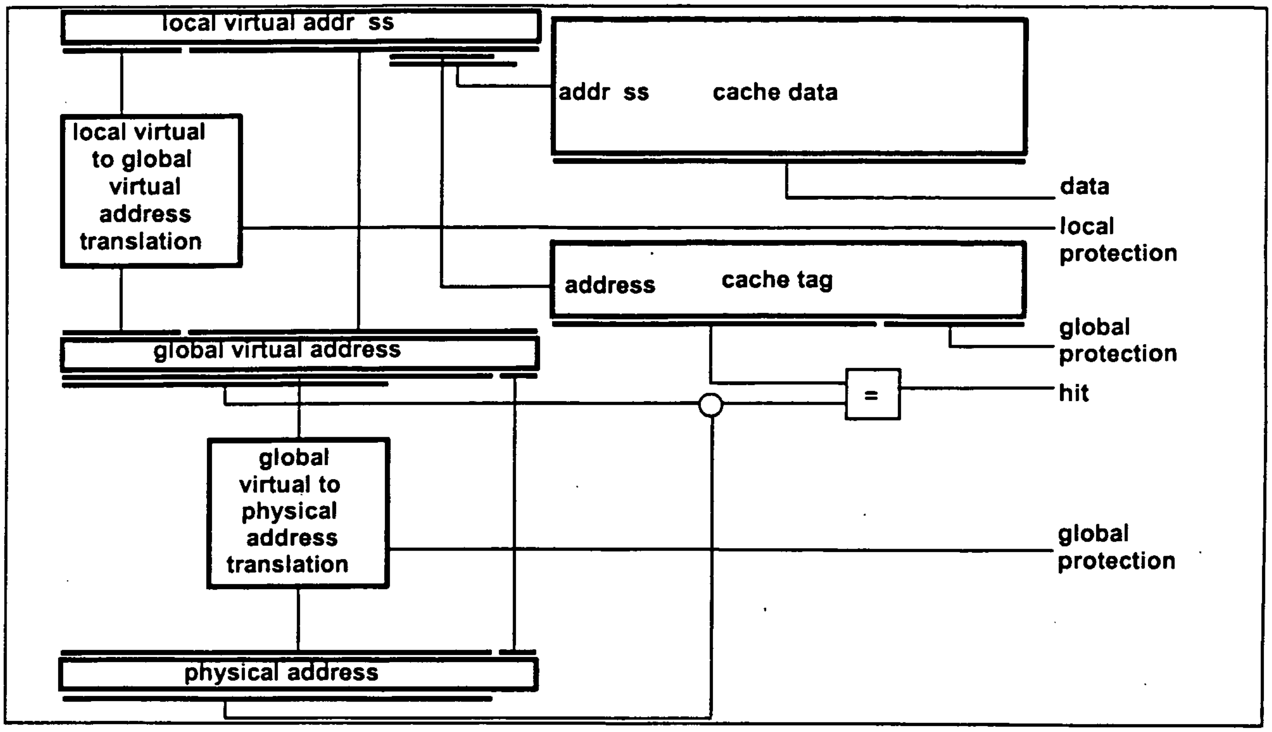

Instruction fetch unit
FIFO
Data fetch unit
FIFO
Execution unit

Fig. 13



memory management organization

Fig. 14

63 … 24	23 … 19	18 … 7	6 … 4	3 … 0
FFFF FFFF 0A00 0000 $_{63..24}$	**th**	**0**	**en**	**b**
40	5	12	3	4

Fig. 15

```
def data,flags ← AccessPhysicalLTB(pa,op,wdata) as
    th ← pa_{23..19}
    en ← pa_{6..4}
    if (en < (1 || 0^{LE})) and (th < T) and (pa_{18..6}=0) then
        case op of
            R:
                data ← 0^{64} || LTBArray[th][en]
            W:
                LocalTB[th][en] ← wdata_{63..0}
        endcase
    else
        data ← 0
    endif
enddef
```

Fig. 16

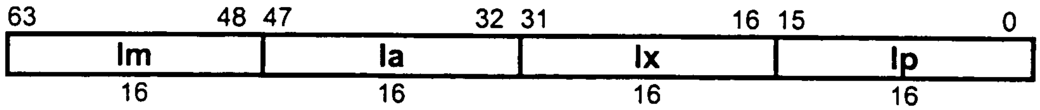


Fig. 17

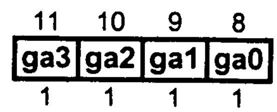


Fig. 18

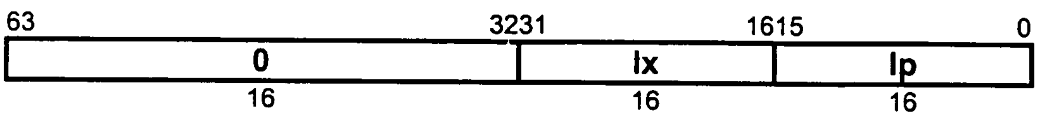


Fig. 19

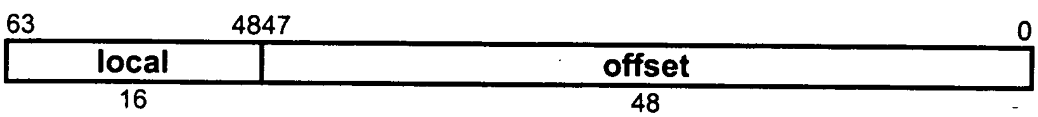


Fig. 20

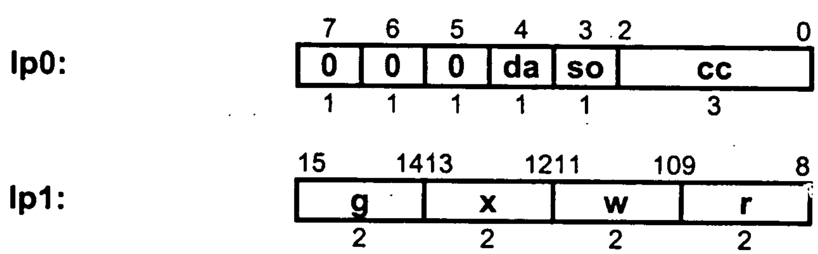


Fig. 21

```
def ga,LocalProtect ← LocalTranslation(th,ba,la,pl) as
    if LB & (ba_{63..48} ⊕ la_{63..48}) then
        raise AccessDisallowedByVirtualAddress
    endif
    me ← NONE
    for i ← 0 to (1 || 0^{LE})-1
        if (la_{63..48} & ~LocalTB[th][i]_{63..48}) = LocalTB[th][i]_{47..32} then
            me ← i
        endif
    endfor
    if me = NONE then
        if ~ControlRegister_{pl+8} then
            raise LocalTBMiss
        endif
        ga ← la
        LocalProtect ← 0
    else
        ga ← (va_{63..48} ^ LocalTB[th][me]_{31..16}) || va_{47..0}
        LocalProtect ← LocalTB[th][me]_{15..0}
    endif
enddef
```

Fig. 22

63 … 24	23 … 19	18 … 4	3 … 0
FFFF FFFF 0C00 0000 $_{63..24}$	th	en	b
40	5	15	4

Fig. 23

```
def data,flags ← AccessPhysicalGTB(pa,op,wdata) as
    th ← pa_{23..19+GT} || 0^{GT}
    en ← pa_{18..4}
    if (en < (1 || 0^{G})) and (th < T) and (pa_{18+GT..19} = 0) then
        case op of
            R:
                data ← GTBArray[th_{5..GT}][en]
            W:
                GTBArray[th_{5..GT}][en] ← wdata
        endcase
    else
        data ← 0
    endif
enddef
```

Fig. 24

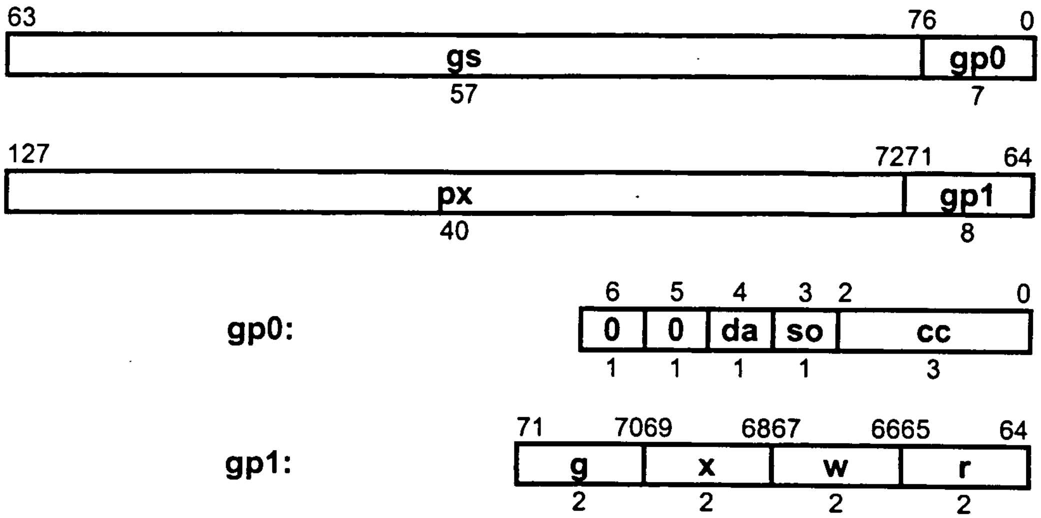


Fig. 25

```
def pa,GlobalProtect ← GlobalAddressTranslation(th,ga,pl,lda) as
    me ← NONE
    for i ← 0 to (1 || 0^G) −1
        if GlobalTB[th5..GT][i] ≠ 0 then
            size ← (GlobalTB[th5..GT][i]63..7 and (0^64-GlobalTB(th5..GT][i]63..7)) || 0^8
            if ((ga63..8||0^8) ^ (GlobalTB[th5..GT][i]63..8||0^8)) and (0^64-size)) = 0 then
                me ← GlobalTB[th5..GT][i]
            endif
        endif
    endfor
    if me = NONE then
        if lda then
            PerformAccessDetail(AccessDetailRequiredByLocalTB)
        endif
        raise GlobalTBMiss
    else
        pa ← (ga63..8 ^ GlobalTB[th5..GT][me]127..72) || ga7..0
        GlobalProtect ← GlobalTB[th5..GT][me]71..64 || 0^1 || GlobalTB[th5..GT][me]6..0
    endif
enddef
```

Fig. 26

```
def GTBUpdateWrite(th,fill,data) as
    me ← NONE
    for i ← 0 to (1 || 0^G) -1
        size ← (GlobalTB[th5..GT][i]63..7 and (0^64-GlobalTB(th5..GT][i]63..7)) || 0^8
        if ((data63..8||0^8) ^ (GlobalTB[th5..GT][i]63..8||0^8)) and (0^64-size) = 0 then
            me ← i
        endif
    endfor
    if me = NONE then
        if fill then
            GlobalTB[th5..GT][GTBLast[th5..GT]] ← data
            GTBLast[th5..GT] ← (GTBLast[th5..GT] + 1)G-1..0
            if GTBLast[th5..GT] = 0 then
                GTBLast[th5..GT] ← GTBFirst[th5..GT]
                GTBBump[th5..GT] ← 1
            endif
        endif
    else
        GlobalTB[th5..GT][me] ← data
    endif
enddef
```

Fig. 27

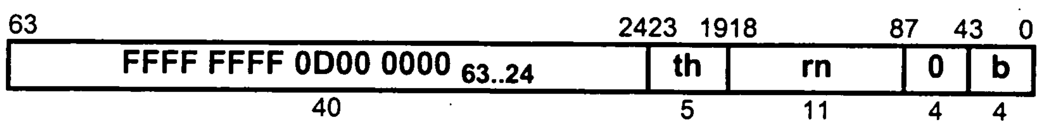


Fig. 28

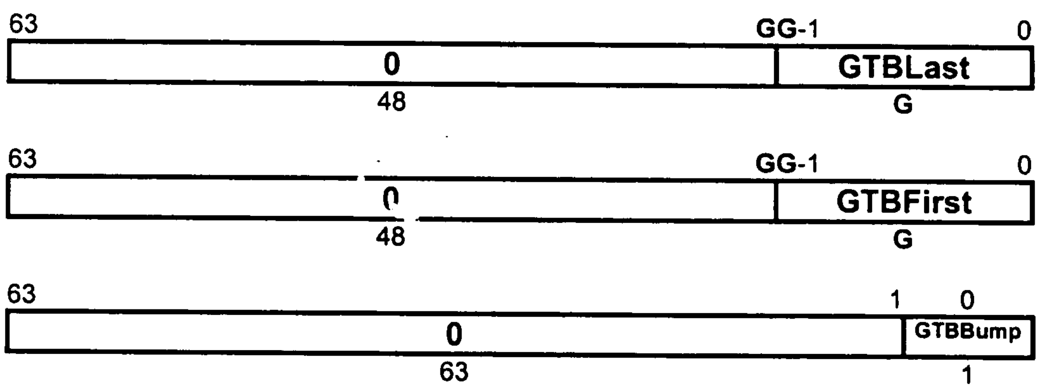


Fig. 29

```
def data,flags ← AccessPhysicalGTBRegisters(pa,op,wdata) as
    th ← pa23..19+GT || 0^GT
    rn ← pa18..8
    if (rn < 5) and (th < T) and (pa18+GT..19 = 0) and (pa7..4 = 0) then
        case rn || op of
            0 || R, 1 || R:
                data ← 0
            0 || W, 1 || W:
                GTBUpdateWrite(th,rn0,wdata)
            2 || R:
                data ← 0^(64-G) || GTBLast[th5..GT]
            2 || W:
                GTBLast[th5..GT] ← wdataG-1..0
            3 || R:
                data ← 0^(64-G) || GTBFirst[th5..GT]
            3 || W:
                GTBFirst[th5..GT] ← wdataG-1..0
            3 || R:
                data ← 0^63 || GTBBump[th5..GT]
            3 || W:
                GTBBump[th5..GT] ← wdata0
        endcase
    else
        data ← 0
    endif
enddef
```

Fig. 30

G.BOOLEAN	Group Boolean

Equivalencies

G.AAA	Group three-way and
G.AAA.1	Group add add add bits
G.AAS.1	Group add add subtract bits
G.ADD.1	Group add bits
G.AND	Group and
G.ANDN	Group and not
G.COPY	Group copy
G.NAAA	Group three-way nand
G.NAND	Group nand
G.NOOO	Group three-way nor
G.NOR	Group nor
G.NOT	Group not
G.NXXX	Group three-way exclusive-nor
G.OOO	Group three-way or
G.OR	Group or
G.ORN	Group or not
G.SAA.1	Group subtract add add bits
G.SAS.1	Group subtract add subtract bits
G.SET	Group set
G.SET.AND.E.1	Group set and equal zero bits
G.SET.AND.NE.1	Group set and not equal zero bits
G.SET.E.1	Group set equal bits
G.SET.G.1	Group set greater signed bits
G.SET.G.U.1	Group set greater unsigned bits
G.SET.G.Z.1	Group set greater zero signed bits
G.SET.GE.1	Group set greater equal signed bits
G.SET.GE.Z.1	Group set greater equal zero signed bits
G.SET.L.1	Group set less signed bits
G.SET.L.Z.1	Group set less zero signed bits
G.SET.LE.1	Group set less equal signed bits
G.SET.LE.U.1	Group set less equal unsigned bits
G.SET.LE.Z.1	Group set less equal zero signed bits
G.SET.NE.1	Group set not equal bits
G.SET.GE.U.1	Group set greater equal unsigned bits
G.SET.L.U.1	Group set less unsigned bits

Fig. 31A

G.SSA.1	Group subtract subtract add bits
G.SSS.1	Group subtract subtract subtract bits
G.SUB.1	Group subtract bits
G.XNOR	Group exclusive-nor
G.XOR	Group exclusive-or
G.XXX	Group three-way exclusive-or
G.ZERO	Group zero

G.AAA rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b10000000
G.AAA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.AAS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.ADD.1 rd=rc,rb	→	G.XOR rd=rc,rb
G.AND rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b10001000
G.ANDN rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01000100
G.BOOLEAN rd@rb,rc,i	→	G.BOOLEAN rd@rc,rb,$i_7i_5i_6i_4i_3i_1i_2i_0$
G.COPY rd=rc	←	G.BOOLEAN rd@rc,rc,0b10001000
G.NAAA. rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b01111111
G.NAND rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01110111
G.NOOO rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b00000001
G.NOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b00010001
G.NOT rd=rc	←	G.BOOLEAN rd@rc,rc,0b00010001
G.NXXX rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b01101001
G.OOO rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b11111110
G.OR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b11101110
G.ORN rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b11011101
G.SAA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SAS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SET rd	←	G.BOOLEAN rd@rd,rd,0b10000001
G.SET.AND.E.1 rd=rb,rc	→	G.NAND rd=rc,rb
G.SET.AND.NE.1 rd=rb,rc	→	G.AND rd=rc,rb
G.SET.E.1 rd=rb,rc	→	G.XNOR rd=rc,rb
G.SET.G.1 rd=rb,rc	→	G.ANDN rd=rc,rb
G.SET.G.U.1 rd=rb,rc	→	G.ANDN rd=rb,rc
G.SET.G.Z.1 rd=rc	→	G.ZERO rd
G.SET.GE.1 rd=rb,rc	→	G.ORN rd=rc,rb
G.SET.GE.Z.1 rd=rc	→	G.NOT rd=rc

Fig. 31A (cont'd)

G.SET.L.1 rd=rb,rc	→	G.ANDN rd=rb,rc
G.SET.L.Z.1 rd=rc	→	G.COPY rd=rc
G.SET.LE.1 rd=rb,rc	→	G.ORN rd=rb,rc
G.SET.LE.U.1 rd=rb,rc	→	G.ORN rd=rc,rb
G.SET.LE.Z.1 rd=rc	→	G.SET rd
G.SET.NE.1 rd=rb,rc	→	G.XOR rd=rc,rb
G.SET.GE.U.1 rd=rb,rc	→	G.ORN rd=rb,rc
G.SET.L.U.1 rd=rb,rc	→	G.ANDN rd=rc,rb
G.SSA.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SSS.1 rd@rc,rb	→	G.XXX rd@rc,rb
G.SUB.1 rd=rc,rb	→	G.XOR rd=rc,rb
G.XNOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b10011001
G.XOR rd=rc,rb	←	G.BOOLEAN rd@rc,rb,0b01100110
G.XXX rd@rc,rb	←	G.BOOLEAN rd@rc,rb,0b10010110
G.ZERO rd	←	G.BOOLEAN rd@rd,rd,0b00000000

Selection

operation	function (binary)	function (decimal)
d	11110000	240
c	11001100	204
b	10101010	176
d&c&b	10000000	128
(d&c)|b	11101010	234
d|c|b	11111110	254
d?c:b	11001010	202
d^c^b	10010110	150
~d^c^b	01101001	105
0	00000000	0

Fig. 31A (cont'd)

Format

G.BOOLEAN rd@trc,trb,f

rd=gbooleani(rd,rc,rb,f)

31 25	24	23 18	17 12	11 6	5 0
G.BOOLEAN	ih	rd	rc	rb	il
7	1	6	6	6	6

```
if f6=f5 then
    if f2=f1 then
        if f2 then
            rc ← max(trc,trb)
            rb ← min(trc,trb)
        else
            rc ← min(trc,trb)
            rb ← max(trc,trb)
        endif
        ih ← 0
        il ← 0 || f6 || f7 || f4 || f3 || f0
    else
        if f2 then
            rc ← trb
            rb ← trc
        else
            rc ← trc
            rb ← trb
        endif
        ih ← 0
        il ← 1 || f6 || f7 || f4 || f3 || f0
    endif
else
    ih ← 1
    if f6 then
        rc ← trb
        rb ← trc
        il ← f1 || f2 || f7 || f4 || f3 || f0
    else
        rc ← trc
        rb ← trb
        il ← f2 || f1 || f7 || f4 || f3 || f0
    endif
endif
```

Fig. 31B

Definition

```
def GroupBoolean (ih,rd,rc,rb,il)
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    if ih=0 then
        if il5=0 then
            f ← il3 || il4 || il4 || il2 || il1 || (rc>rb)^2 || il0
        else
            f ← il3 || il4 || il4 || il2 || il1 || 0 || 1 || il0
        endif
    else
        f ← il3 || 0 || 1 || il2 || il1 || il5 || il4 || il0
    endif
    for i ← 0 to 127 by size
        ai ← f(di||ci||bi)
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig. 31C

Operation codes

G.MUX	Group multiplex

Redundancies

G.MUX ra=rd,rc,rc	⇔	*G.COPY ra=rc*
G.MUX ra=ra,rc,rb	⇔	G.BOOLEAN ra@rc,rb,0x11001010
G.MUX ra=rd,ra,rb	⇔	G.BOOLEAN ra@rd,rb,0x11100010
G.MUX ra=rd,rc,ra	⇔	G.BOOLEAN ra@rd,rc,0x11011000
G.MUX ra=rd,rd,rb	⇔	G.OR ra=rd,rb
G.MUX ra=rd,rc,rd	⇔	G.AND ra=rd,rc

Format

G.MUX ra=rd,rc,rb

ra=gmux(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
G.MUX	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 31D

Definition

```
def GroupTernary(op,size,rd,rc,rb,ra) as
	d ← RegRead(rd, 128)
	c ← RegRead(rc, 128)
	b ← RegRead(rb, 128)
	case op of
		G.MUX:
			a ← (c and d) or (b and not d)
	endcase
	RegWrite(ra, 128, a)
enddef
```

Exceptions

none

Fig. 31D

G.ADD.8	Group add bytes
G.ADD.16	Group add doublets
G.ADD.32	Group add quadlets
G.ADD.64	Group add octlets
G.ADD.128	Group add hexlet
G.ADD.L.8	Group add limit signed bytes
G.ADD.L.16	Group add limit signed doublets
G.ADD.L.32	Group add limit signed quadlets
G.ADD.L.64	Group add limit signed octlets
G.ADD.L.128	Group add limit signed hexlet
G.ADD.L.U.8	Group add limit unsigned bytes
G.ADD.L.U.16	Group add limit unsigned doublets
G.ADD.L.U.32	Group add limit unsigned quadlets
G.ADD.L.U.64	Group add limit unsigned octlets
G.ADD.L.U.128	Group add limit unsigned hexlet
G.ADD.8.O	Group add signed bytes check overflow
G.ADD.16.O	Group add signed doublets check overflow
G.ADD.32.O	Group add signed quadlets check overflow
G.ADD.64.O	Group add signed octlets check overflow
G.ADD.128.O	Group add signed hexlet check overflow
G.ADD.U.8.O	Group add unsigned bytes check overflow
G.ADD.U.16.O	Group add unsigned doublets check overflow
G.ADD.U.32.O	Group add unsigned quadlets check overflow
G.ADD.U.64.O	Group add unsigned octlets check overflow
G.ADD.U.128.O	Group add unsigned hexlet check overflow

Fig. 32A

Format

G.op.size rd=rc,rb

rd=gopsize(rc,rb)

31 24	23 18	17 12	11 6	5 0
G.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

Fig. 32B

Definition

def Group(op,size,rd,rc,rb)
    $c \leftarrow$ RegRead(rc, 128)
    $b \leftarrow$ RegRead(rb, 128)
    case op of
        G.ADD:
            for $i \leftarrow 0$ to 128-size by size
                $a_{i+size-1..i} \leftarrow c_{i+size-1..i} + b_{i+size-1..i}$
            endfor
        G.ADD.L:
            for $i \leftarrow 0$ to 128-size by size
                $t \leftarrow (c_{i+size-1} \parallel c_{i+size-1..i}) + (b_{i+size-1} \parallel b_{i+size-1..i})$
                $a_{i+size-1..i} \leftarrow (t_{size} \neq t_{size-1})\ ?\ (t_{size} \parallel t_{size-1}^{size-1}) : t_{size-1..0}$
            endfor
        G.ADD.L.U:
            for $i \leftarrow 0$ to 128-size by size
                $t \leftarrow (0^1 \parallel c_{i+size-1..i}) + (0^1 \parallel b_{i+size-1..i})$
                $a_{i+size-1..i} \leftarrow (t_{size} \neq 0)\ ?\ (1^{size}) : t_{size-1..0}$
            endfor
        G.ADD.O:
            for $i \leftarrow 0$ to 128-size by size
                $t \leftarrow (c_{i+size-1} \parallel c_{i+size-1..i}) + (b_{i+size-1} \parallel b_{i+size-1..i})$
                if $t_{size} \neq t_{size-1}$ then
                    raise FixedPointArithmetic
                endif
                $a_{i+size-1..i} \leftarrow t_{size-1..0}$
            endfor
        G.ADD.U.O:
            for $i \leftarrow 0$ to 128-size by size
                $t \leftarrow (0^1 \parallel c_{i+size-1..i}) + (0^1 \parallel b_{i+size-1..i})$
                if $t_{size} \neq 0$ then
                    raise FixedPointArithmetic
                endif
                $a_{i+size-1..i} \leftarrow t_{size-1..0}$
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef

Exceptions

Fixed-point arithmetic

Fig. 32C

Operation codes

G.SET.AND.E.8	Group set and equal zero bytes
G.SET.AND.E.16	Group set and equal zero doublets
G.SET.AND.E.32	Group set and equal zero quadlets
G.SET.AND.E.64	Group set and equal zero octlets
G.SET.AND.E.128	Group set and equal zero hexlet
G.SET.AND.NE.8	Group set and not equal zero bytes
G.SET.AND.NE.16	Group set and not equal zero doublets
G.SET.AND.NE.32	Group set and not equal zero quadlets
G.SET.AND.NE.64	Group set and not equal zero octlets
G.SET.AND.NE.128	Group set and not equal zero hexlet
G.SET.E.8	Group set equal bytes
G.SET.E.16	Group set equal doublets
G.SET.E.32	Group set equal quadlets
G.SET.E.64	Group set equal octlets
G.SET.E.128	Group set equal hexlet
G.SET.GE.8	Group set greater equal signed bytes
G.SET.GE.16	Group set greater equal signed doublets
G.SET.GE.32	Group set greater equal signed quadlets
G.SET.GE.64	Group set greater equal signed octlets
G.SET.GE.128	Group set greater equal signed hexlet
G.SET.GE.U.8	Group set greater equal unsigned bytes
G.SET.GE.U.16	Group set greater equal unsigned doublets
G.SET.GE.U.32	Group set greater equal unsigned quadlets
G.SET.GE.U.64	Group set greater equal unsigned octlets
G.SET.GE.U.128	Group set greater equal unsigned hexlet
G.SET.L.8	Group set signed less bytes
G.SET.L.16	Group set signed less doublets
G.SET.L.32	Group set signed less quadlets
G.SET.L.64	Group set signed less octlets
G.SET.L.128	Group set signed less hexlet
G.SET.L.U.8	Group set less unsigned bytes
G.SET.L.U.16	Group set less unsigned doublets
G.SET.L.U.32	Group set less unsigned quadlets
G.SET.L.U.64	Group set less unsigned octlets
G.SET.L.U.128	Group set less unsigned hexlet
G.SET.NE.8	Group set not equal bytes
G.SET.NE.16	Group set not equal doublets

Fig. 33A

G.SET.NE.32	Group set not equal quadlets
G.SET.NE.64	Group set not equal octlets
G.SET.NE.128	Group set not equal hexlet
G.SUB.8	Group subtract bytes
G.SUB.8.O	Group subtract signed bytes check overflow
G.SUB.16	Group subtract doublets
G.SUB.16.O	Group subtract signed doublets check overflow
G.SUB.32	Group subtract quadlets
G.SUB.32.O	Group subtract signed quadlets check overflow
G.SUB.64	Group subtract octlets
G.SUB.64.O	Group subtract signed octlets check overflow
G.SUB.128	Group subtract hexlet
G.SUB.128.O	Group subtract signed hexlet check overflow
G.SUB.L.8	Group subtract limit signed bytes
G.SUB.L.16	Group subtract limit signed doublets
G.SUB.L.32	Group subtract limit signed quadlets
G.SUB.L.64	Group subtract limit signed octlets
G.SUB.L.128	Group subtract limit signed hexlet
G.SUB.L.U.8	Group subtract limit unsigned bytes
G.SUB.L.U.16	Group subtract limit unsigned doublets
G.SUB.L.U.32	Group subtract limit unsigned quadlets
G.SUB.L.U.64	Group subtract limit unsigned octlets
G.SUB.L.U.128	Group subtract limit unsigned hexlet
G.SUB.U.8.O	Group subtract unsigned bytes check overflow
G.SUB.U.16.O	Group subtract unsigned doublets check overflow
G.SUB.U.32.O	Group subtract unsigned quadlets check overflow
G.SUB.U.64.O	Group subtract unsigned octlets check overflow
G.SUB.U.128.O	Group subtract unsigned hexlet check overflow

Fig. 33A (cont'd)

Equivalencies

G.SET.E.Z.8	Group set equal zero bytes
G.SET.E.Z.16	Group set equal zero doublets
G.SET.E.Z.32	Group set equal zero quadlets
G.SET.E.Z.64	Group set equal zero octlets
G.SET.E.Z.128	Group set equal zero hexlet
G.SET.G.Z.8	Group set greater zero signed bytes
G.SET.G.Z.16	Group set greater zero signed doublets
G.SET.G.Z.32	Group set greater zero signed quadlets
G.SET.G.Z.64	Group set greater zero signed octlets
G.SET.G.Z.128	Group set greater zero signed hexlet
G.SET.GE.Z.8	Group set greater equal zero signed bytes
G.SET.GE.Z.16	Group set greater equal zero signed doublets
G.SET.GE.Z.32	Group set greater equal zero signed quadlets
G.SET.GE.Z.64	Group set greater equal zero signed octlets
G.SET.GE.Z.128	Group set greater equal zero signed hexlet
G.SET.L.Z.8	Group set less zero signed bytes
G.SET.L.Z.16	Group set less zero signed doublets
G.SET.L.Z.32	Group set less zero signed quadlets
G.SET.L.Z.64	Group set less zero signed octlets
G.SET.L.Z.128	Group set less zero signed hexlet
G.SET.LE.Z.8	Group set less equal zero signed bytes
G.SET.LE.Z.16	Group set less equal zero signed doublets
G.SET.LE.Z.32	Group set less equal zero signed quadlets
G.SET.LE.Z.64	Group set less equal zero signed octlets
G.SET.LE.Z.128	Group set less equal zero signed hexlet
G.SET.NE.Z.8	Group set not equal zero bytes
G.SET.NE.Z.16	Group set not equal zero doublets
G.SET.NE.Z.32	Group set not equal zero quadlets
G.SET.NE.Z.64	Group set not equal zero octlets
G.SET.NE.Z.128	Group set not equal zero hexlet

Fig. 33A (cont'd)

G.SET.LE.8	Group set less equal signed bytes
G.SET.LE.16	Group set less equal signed doublets
G.SET.LE.32	Group set less equal signed quadlets
G.SET.LE.64	Group set less equal signed octlets
G.SET.LE.128	Group set less equal signed hexlet
G.SET.LE.U.8	Group set less equal unsigned bytes
G.SET.LE.U.16	Group set less equal unsigned doublets
G.SET.LE.U.32	Group set less equal unsigned quadlets
G.SET.LE.U.64	Group set less equal unsigned octlets
G.SET.LE.U.128	Group set less equal unsigned hexlet
G.SET.G.8	Group set signed greater bytes
G.SET.G.16	Group set signed greater doublets
G.SET.G.32	Group set signed greater quadlets
G.SET.G.64	Group set signed greater octlets
G.SET.G.128	Group set signed greater hexlet
G.SET.G.U.8	Group set greater unsigned bytes
G.SET.G.U.16	Group set greater unsigned doublets
G.SET.G.U.32	Group set greater unsigned quadlets
G.SET.G.U.64	Group set greater unsigned octlets
G.SET.G.U.128	Group set greater unsigned hexlet

G.SET.E.Z.size rd=rc	←	G.SET.AND.E.size rd=rc,rc
G.SET.G.Z.size rd=rc	⇐	G.SET.L.U.size rd=rc,rc
G.SET.GE.Z.size rd=rc	⇐	G.SET.GE.size rd=rc,rc
G.SET.L.Z.size rd=rc	⇐	G.SET.L.size rd=rc,rc
G.SET.LE.Z.size rd=rc	⇐	G.SET.GE.U.size rd=rc,rc
G.SET.NE.Z.size rd=rc	←	G.SET.AND.NE.size rd=rc,rc
G.SET.G.size rd=rb,rc	→	G.SET.L.size rd=rc,rb
G.SET.G.U.size rd=rb,rc	→	G.SET.L.U.size rd=rc,rb
G.SET.LE.size rd=rb,rc	→	G.SET.GE.size rd=rc,rb
G.SET.LE.U.size rd=rb,rc	→	G.SET.GE.U.size rd=rc,rb

Fig. 33A (cont'd)

Format

G.op.size rd=rb,rc

rd=gopsize(rb,rc)

31 24	23 18	17 12	11 6	5 0
G.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

Fig. 33B

Definition

```
def GroupReversed(op,size,rd,rc,rb)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case op of
        G.SUB:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← b_{i+size-1..i} - c_{i+size-1..i}
            endfor
        G.SUB.L:
            for i ← 0 to 128-size by size
                t ← (b_{i+size-1} || b_{i+size-1..i}) - (c_{i+size-1} || c_{i+size-1..i})
                a_{i+size-1..i} ← (t_{size} ≠ t_{size-1}) ? (t_{size} || t_{size}^{size-1}) : t_{size-1..0}
            endfor
        G.SUB.LU:
            for i ← 0 to 128-size by size
                t ← (0^{1} || b_{i+size-1..i}) - (0^{1} || c_{i+size-1..i})
                a_{i+size-1..i} ← (t_{size} ≠ 0) ? 0^{size}: t_{size-1..0}
            endfor
        G.SUB.O:
            for i ← 0 to 128-size by size
                t ← (b_{i+size-1} || b_{i+size-1..i}) - (c_{i+size-1} || c_{i+size-1..i})
                if (t_{size} ≠ t_{size-1}) then
                    raise FixedPointArithmetic
                endif
                a_{i+size-1..i} ← t_{size-1..0}
            endfor
        G.SUB.U.O:
            for i ← 0 to 128-size by size
                t ← (0^{1} || b_{i+size-1..i}) - (0^{1} || c_{i+size-1..i})
                if (t_{size} ≠ 0) then
                    raise FixedPointArithmetic
                endif
                a_{i+size-1..i} ← t_{size-1..0}
            endfor
        G.SET.E:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← (b_{i+size-1..i} = c_{i+size-1..i})^{size}
            endfor
        G.SET.NE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← (b_{i+size-1..i} ≠ c_{i+size-1..i})^{size}
            endfor
        G.SET.AND.E:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((b_{i+size-1..i} and c_{i+size-1..i}) = 0)^{size}
            endfor
```

Fig. 33C

```
        G.SET.AND.NE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((b_{i+size-1..i} and c_{i+size-1..i}) ≠ 0)^size
            endfor
        G.SET.L:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} < 0) : (b_{i+size-1..i} < c_{i+size-1..i}))^size
            endfor
        G.SET.GE:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} ≥ 0) : (b_{i+size-1..i} ≥ c_{i+size-1..i}))^size
            endfor
        G.SET.L.U:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} > 0) :
                    ((0 || b_{i+size-1..i}) < (0 || c_{i+size-1..i})))^size
            endfor
        G.SET.GE.U:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← ((rc = rb) ? (b_{i+size-1..i} ≤ 0) :
                    ((0 || b_{i+size-1..i}) ≥ (0 || c_{i+size-1..i})))^size
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Fixed-point arithmetic

Fig. 33C (cont'd)

E.DIV.64	Ensemble divide signed octlets
E.DIV.U.64	Ensemble divide unsigned octlets
E.MUL.8	Ensemble multiply signed bytes
E.MUL.16	Ensemble multiply signed doublets
E.MUL.32	Ensemble multiply signed quadlets
E.MUL.64	Ensemble multiply signed octlets
E.MUL.SUM.8	Ensemble multiply sum signed bytes
E.MUL.SUM.16	Ensemble multiply sum signed doublets
E.MUL.SUM.32	Ensemble multiply sum signed quadlets
E.MUL.SUM.64	Ensemble multiply sum signed octlets
E.MUL.C.8	Ensemble complex multiply bytes
E.MUL.C.16	Ensemble complex multiply doublets
E.MUL.C.32	Ensemble complex multiply quadlets
E.MUL.M.8	Ensemble multiply mixed-signed bytes
E.MUL.M.16	Ensemble multiply mixed-signed doublets
E.MUL.M.32	Ensemble multiply mixed-signed quadlets
E.MUL.M.64	Ensemble multiply mixed-signed octlets
E.MUL.P.8	Ensemble multiply polynomial bytes
E.MUL.P.16	Ensemble multiply polynomial doublets
E.MUL.P.32	Ensemble multiply polynomial quadlets
E.MUL.P.64	Ensemble multiply polynomial octlets
E.MUL.SUM.C.8	Ensemble multiply sum complex bytes
E.MUL.SUM.C.16	Ensemble multiply sum complex doublets
E.MUL.SUM.C.32	Ensemble multiply sum complex quadlets
E.MUL.SUM.M.8	Ensemble multiply sum mixed-signed bytes
E.MUL.SUM.M.16	Ensemble multiply sum mixed-signed doublets
E.MUL.SUM.M.32	Ensemble multiply sum mixed-signed quadlets
E.MUL.SUM.M.64	Ensemble multiply sum mixed-signed octlets
E.MUL.SUM.U.8	Ensemble multiply sum unsigned bytes
E.MUL.SUM.U.16	Ensemble multiply sum unsigned doublets
E.MUL.SUM.U.32	Ensemble multiply sum unsigned quadlets
E.MUL.SUM.U.64	Ensemble multiply sum unsigned octlets
E.MUL.U.8	Ensemble multiply unsigned bytes
E.MUL.U.16	Ensemble multiply unsigned doublets
E.MUL.U.32	Ensemble multiply unsigned quadlets
E.MUL.U.64	Ensemble multiply unsigned octlets

Fig. 34A

Format

E.op.size rd=rc,rb

rd=eopsize(rc,rb)

31 24	23 18	17 12	11 6	5 0
E.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

Fig. 34B

Definition

```
def mul(size,h,vs,v,i,ws,w,j) as
        mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def c ← PolyMultiply(size,a,b) as
        p[0] ← 0^{2*size}
        for k ← 0 to size-1
                p[k+1] ← p[k] ^ a_k ? (0^{size-k} || b || 0^k) : 0^{2*size}
        endfor
        c ← p[size]
enddef

def Ensemble(op,size,rd,rc,rb)
        c ← RegRead(rc, 128)
        b ← RegRead(rb, 128)
        case op of
                E.MUL:, E.MUL.C:, EMUL.SUM, E.MUL.SUM.C, E.CON, E.CON.C, E.DIV:
                        cs ← bs ← 1
                E.MUL.M:, EMUL.SUM.M, E.CON.M:
                        cs ← 0
                        bs ← 1
                E.MUL.U:, EMUL.SUM.U, E.CON.U, E.DIV.U, E.MUL.P:
                        cs ← bs ← 0
        endcase
        case op of
                E.MUL, E.MUL.U, E.MUL.M:
                        for i ← 0 to 64-size by size
                                d_{2*(i+size)-1..2*i} ← mul(size,2*size,cs,c,i,bs,b,i)
                        endfor
                E.MUL.P:
                        for i ← 0 to 64-size by size
                                d_{2*(i+size)-1..2*i} ← PolyMultiply(size,c_{size-1+i..i},b_{size-1+i..i})
                        endfor
                E.MUL.C:
                        for i ← 0 to 64-size by size
                                if (i and size) = 0 then
                                        p ← mul(size,2*size,1,c,i,1,b,i) - mul(size,2*size,1,c,i+size,1,b,i+size)
                                else
                                        p ← mul(size,2*size,1,c,i,1,b,i+size) + mul(size,2*size,1,c,i,1,b,i+size)
                                endif
                                d_{2*(i+size)-1..2*i} ← p
                        endfor
                E.MUL.SUM, E.MUL.SUM.U, E.MUL.SUM.M:
                        p[0] ← 0^{128}
                        for i ← 0 to 128-size by size
                                p[i+size] ← p[i] + mul(size,128,cs,c,i,bs,b,i)
                        endfor
                        a ← p[128]
                E.MUL.SUM.C:
                        p[0] ← 0^{64}
                        p[size] ← 0^{64}
                        for i ← 0 to 128-size by size
                                if (i and size) = 0 then
                                        p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i)
                                                        - mul(size,64,1,c,i+size,1,b,i+size)
                                else
                                        p[i+2*size] ← p[i] + mul(size,64,1,c,i,1,b,i+size)
                                                        + mul(size,64,1,c,i+size,1,b,i)
                                endif
                        endfor
                        a ← p[128+size] || p[128]
```

Fig. 34C

```
            E.CON, E.CON.U, E.CON.M:
                p[0] ← 0^128
                for j ← 0 to 64-size by size
                    for i ← 0 to 64-size by size
                        p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                            mul(size,2*size,cs,c,i+64-j,bs,b,j)
                    endfor
                endfor
                a ← p[64]
            E.CON.C:
                p[0] ← 0^128
                for j ← 0 to 64-size by size
                    for i ← 0 to 64-size by size
                        if ((~i) and j and size) = 0 then
                            p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i +
                                mul(size,2*size,1,c,i+64-j,1,b,j)
                        else
                            p[j+size]2*(i+size)-1..2*i ← p[j]2*(i+size)-1..2*i -
                                mul(size,2*size,1,c,i+64-j+2*size,1,b,j)
                        endif
                    endfor
                endfor
                a ← p[64]
            E.DIV:
                if (b = 0) or ( (c = (1||0^63)) and (b = 1^64) ) then
                    a ← undefined
                else
                    q ← c / b
                    r ← c - q*b
                    a ← r63..0 || q63..0
                endif
            E.DIV.U:
                if b = 0 then
                    a ← undefined
                else
                    q ← (0 || c) / (0 || b)
                    r ← c - (0 || q)*(0 || b)
                    a ← r63..0 || q63..0
                endif
        endcase
        RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig. 34C (cont'd)

G.COM.AND.E.8	Group compare and equal zero bytes
G.COM.AND.E.16	Group compare and equal zero doublets
G.COM.AND.E.32	Group compare and equal zero quadlets
G.COM.AND.E.64	Group compare and equal zero octlets
G.COM.AND.E.128	Group compare and equal zero hexlet
G.COM.AND.NE.8	Group compare and not equal zero bytes
G.COM.AND.NE.16	Group compare and not equal zero doublets
G.COM.AND.NE.32	Group compare and not equal zero quadlets
G.COM.AND.NE.64	Group compare and not equal zero octlets
G.COM.AND.NE.128	Group compare and not equal zero hexlet
G.COM.E.8	Group compare equal bytes
G.COM.E.16	Group compare equal doublets
G.COM.E.32	Group compare equal quadlets
G.COM.E.64	Group compare equal octlets
G.COM.E.128	Group compare equal hexlet
G.COM.GE.8	Group compare greater equal signed bytes
G.COM.GE.16	Group compare greater equal signed doublets
G.COM.GE.32	Group compare greater equal signed quadlets
G.COM.GE.64	Group compare greater equal signed octlets
G.COM.GE.128	Group compare greater equal signed hexlet
G.COM.GE.U.8	Group compare greater equal unsigned bytes
G.COM.GE.U.16	Group compare greater equal unsigned doublets
G.COM.GE.U.32	Group compare greater equal unsigned quadlets
G.COM.GE.U.64	Group compare greater equal unsigned octlets
G.COM.GE.U.128	Group compare greater equal unsigned hexlet
G.COM.L.8	Group compare signed less bytes
G.COM.L.16	Group compare signed less doublets
G.COM.L.32	Group compare signed less quadlets
G.COM.L.64	Group compare signed less octlets
G.COM.L.128	Group compare signed less hexlet
G.COM.L.U.8	Group compare less unsigned bytes
G.COM.L.U.16	Group compare less unsigned doublets
G.COM.L.U.32	Group compare less unsigned quadlets
G.COM.L.U.64	Group compare less unsigned octlets
G.COM.L.U.128	Group compare less unsigned hexlet
G.COM.NE.8	Group compare not equal bytes
G.COM.NE.16	Group compare not equal doublets
G.COM.NE.32	Group compare not equal quadlets
G.COM.NE.64	Group compare not equal octlets
G.COM.NE.128	Group compare not equal hexlet

Fig. 35A

Format

G.COM.op.size rd,rc
G.COM.opz.size rcd

gcomopsize(rd,rc)

31 24	23 18	17 12	11 6	5 0
G.size	**rd**	**rc**	**op**	**GCOM**
8	6	6	6	6

Fig. 35B

Definition

```
def GroupCompare(op,size,rd,rc)
	d ← RegRead(rd, 128)
	c ← RegRead(rc, 128)
	case op of
		G.COM.E:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← (d_{i+size-1..i} = c_{i+size-1..i})^size
			endfor
		G.COM.NE:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← (d_{i+size-1..i} ≠ c_{i+size-1..i})^size
			endfor
		G.COM.AND.E:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((c_{i+size-1..i} and d_{i+size-1..i}) = 0)^size
			endfor
		G.COM.AND.NE:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((c_{i+size-1..i} and d_{i+size-1..i}) ≠ 0)^size
			endfor
		G.COM.L:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((rd = rc) ? (c_{i+size-1..i} < 0) : (d_{i+size-1..i} < c_{i+size-1..i}))^size
			endfor
		G.COM.GE:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((rd = rc) ? (c_{i+size-1..i} ≥ 0) : (d_{i+size-1..i} ≥ c_{i+size-1..i}))^size
			endfor
		G.COM.L.U:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((rd = rc) ? (c_{i+size-1..i} > 0) :
					((0 || d_{+size-1..i}) < (0 || c_{i+size-1..i})))^size
			endfor
		G.COM.GE.U:
			for i ← 0 to 128-size by size
				a_{i+size-1..i} ← ((rd = rc) ? (c_{i+size-1..i} ≤ 0) :
					((0 || d_{i+size-1..i}) ≥ (0 || c_{i+size-1..i})))^size
			endfor
	endcase
	if (a ≠ 0) then
		raise FixedPointArithmetic
	endif
enddef
```

Exceptions

Fixed-point arithmetic

Fig. 35C

E.LOG.MOST.8	Ensemble log of most significant bit signed bytes
E.LOG.MOST.16	Ensemble log of most significant bit signed doublets
E.LOG.MOST.32	Ensemble log of most significant bit signed quadlets
E.LOG.MOST.64	Ensemble log of most significant bit signed octlets
E.LOG.MOST.128	Ensemble log of most significant bit signed hexlet
E.LOG.MOST.U.8	Ensemble log of most significant bit unsigned bytes
E.LOG.MOST.U.16	Ensemble log of most significant bit unsigned doublets
E.LOG.MOST.U.32	Ensemble log of most significant bit unsigned quadlets
E.LOG.MOST.U.64	Ensemble log of most significant bit unsigned octlets
E.LOG.MOST.U.128	Ensemble log of most significant bit unsigned hexlet
E.SUM.8	Ensemble sum signed bytes
E.SUM.16	Ensemble sum signed doublets
E.SUM.32	Ensemble sum signed quadlets
E.SUM.64	Ensemble sum signed octlets
E.SUM.U.1	Ensemble sum unsigned bits
E.SUM.U.8	Ensemble sum unsigned bytes
E.SUM.U.16	Ensemble sum unsigned doublets
E.SUM.U.32	Ensemble sum unsigned quadlets
E.SUM.U.64	Ensemble sum unsigned octlets

Selection

class	op	size
sum	SUM	8 16 32 64
	SUM.U	1 8 16 32 64
log most significant bit	LOG.MOST LOG.MOST.U	8 16 32 64 128

Fig. 36A

Format

E.op.size rd=rc

rd=eopsize(rc)

31 24	23 18	17 12	11 6	5 0
E.size	rd	rc	op	E.UNARY
8	6	6	6	6

Fig. 36B

Definition

```
def EnsembleUnary(op,size,rd,rc)
    c ← RegRead(rc, 128)
    case op of
        E.LOG.MOST:
            for i ← 0 to 128-size by size
                if (c_{i+size-1..i} =0) then
                    a_{i+size-1..i} ← -1
                else
                    for j ← 0 to size-1
                        if c_{size-1+i..j+i} = (c_{size-1+i}^{size-1-j} || not c_{size-1+l}) then
                            a_{i+size-1..i} ← j
                        endif
                    endfor
                endif
            endfor
        E.LOG.MOSTU:
            for i ← 0 to 128-size by size
                if (c_{i+size-1..i} =0) then
                    a_{i+size-1..i} ← -1
                else
                    for j ← 0 to size-1
                        if c_{size-1+i..j+i} = (0^{size-1-j} || 1) then
                            a_{i+size-1..i} ← j
                        endif
                    endfor
                endif
            endfor
        E.SUM:
            p[0] ← 0^{128}
            for i ← 0 to 128-size by size
                p[i+size] ← p[i] + (c_{size-1+i}^{128-size} || c_{size-1+i..i})
            endfor
            a ← p[128]
        E.SUMU:
            p[0] ← 0^{128}
            for i ← 0 to 128-size by size
                p[i+size] ← p[i] + (0^{128-size} || c_{size-1+i..i})
            endfor
            a ← p[128]
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig. 36C

Floating-point function Definitions

```
def eb ← ebits(prec) as
        case pref of
                16:
                        eb ← 5
                32:
                        eb ← 8
                64:
                        eb ← 11
                128:
                        eb ← 15
        endcase
enddef

def eb ← ebias(prec) as
        eb ← 0 || 1^(ebits(prec)-1)
enddef

def fb ← fbits(prec) as
        fb ← prec – 1 – eb
enddef

def a ← F(prec, ai) as
        a.s ← ai_(prec-1)
        ae ← ai_(prec-2..fbits(prec))
        af ← ai_(fbits(prec)-1..0)
        if ae = 1^(ebits(prec)) then
                if af = 0 then
                        a.t ← INFINITY
                elseif af_(fbits(prec)-1) then
                        a.t ← SNaN
                        a.e ← -fbits(prec)
                        a.f ← 1 || af_(fbits(prec)-2..0)
                else
                        a.t ← QNaN
                        a.e ← -fbits(prec)
                        a.f ← af
                endif
```

Fig. 37

```
elseif ae = 0 then
        if af = 0 then
                a.t ← ZERO
        else
                a.t ← NORM
                a.e ← 1-ebias(prec)-fbits(prec)
                a.f ← 0 || af
        endif
else
        a.t ← NORM
        a.e ← ae-ebias(prec)-fbits(prec)
        a.f ← 1 || af
endif
enddef

def a ← DEFAULTQNAN as
        a.s ← 0
        a.t ← QNAN
        a.e ← -1
        a.f ← 1
enddef

def a ← DEFAULTSNAN as
        a.s ← 0
        a.t ← SNAN
        a.e ← -1
        a.f ← 1
enddef

def fadd(a,b) as faddr(a,b,N) enddef

def c ← faddr(a,b,round) as
        if a.t=NORM and b.t=NORM then
                // d,e are a,b with exponent aligned and fraction adjusted
                if a.e > b.e then
                        d ← a
                        e.t ← b.t
                        e.s ← b.s
                        e.e ← a.e
                        e.f ← b.f || 0^(a.e-b.e)
                else if a.e < b.e then
                        d.t ← a.t
                        d.s ← a.s
                        d.e ← b.e
                        d.f ← a.f || 0^(b.e-a.e)
                        e ← b
                endif
                c.t ← d.t
                c.e ← d.e
                if d.s = e.s then
                        c.s ← d.s
                        c.f ← d.f + e.f
                elseif d.f > e.f then
                        c.s ← d.s
                        c.f ← d.f – e.f
```

Fig. 37 (c nt'd)

```
            elseif d.f < e.f then
                  c.s ← e.s
                  c.f ← e.f – d.f
            else
                  c.s ← r=F
                  c.t ← ZERO
            endif
      // priority is given to b operand for NaN propagation
      elseif (b.t=SNAN) or (b.t=QNAN) then
            c ← b
      elseif (a.t=SNAN) or (a.t=QNAN) then
            c ← a
      elseif a.t=ZERO and b.t=ZERO then
            c.t ← ZERO
            c.s ← (a.s and b.s) or (round=F and (a.s or b.s))
      // NULL values are like zero, but do not combine with ZERO to alter sign
      elseif a.t=ZERO or a.t=NULL then
            c ← b
      elseif b.t=ZERO or b.t=NULL then
            c ← a
      elseif a.t=INFINITY and b.t=INFINITY then
            if a.s ≠ b.s then
                  c ← DEFAULTSNAN // Invalid
            else
                  c ← a
            endif
      elseif a.t=INFINITY then
            c ← a
      elseif b.t=INFINITY then
            c ← b
      else
            assert FALSE // should have covered al the cases above
      endif
enddef

def b ← fneg(a) as
      b.s ← ~a.s
      b.t ← a.t
      b.e ← a.e
      b.f ← a.f
enddef

def fsub(a,b) as fsubr(a,b,N) enddef

def fsubr(a,b,round) as faddr(a,fneg(b),round) enddef

def frsub(a,b) as frsubr(a,b,N) enddef

def frsubr(a,b,round) as faddr(fneg(a),b,round) enddef

def c ← fcom(a,b) as
      if (a.t=SNAN) or (a.t=QNAN) or (b.t=SNAN) or (b.t=QNAN) then
            c ← U
      elseif a.t=INFINITY and b.t=INFINITY then
            if a.s ≠ b.s then
                  c ← (a.s=0) ? G: L
```

Fig. 37 (cont'd)

```
            else
                    c ← E
            endif
    elseif a.t=INFINITY then
            c ← (a.s=0) ? G: L
    elseif b.t=INFINITY then
            c ← (b.s=0) ? G: L
    elseif a.t=NORM and b.t=NORM then
            if a.s ≠ b.s then
                    c ← (a.s=0) ? G: L
            else
                    if a.e > b.e then
                            af ← a.f
                            bf ← b.f || 0^(a.e-b.e)
                    else
                            af ← a.f || 0^(b.e-a.e)
                            bf ← b.f
                    endif
                    if af = bf then
                            c ← E
                    else
                            c ← ((a.s=0) ^ (af > bf)) ? G : L
                    endif
            endif
    elseif a.t=NORM then
            c ← (a.s=0) ? G: L
    elseif b.t=NORM then
            c ← (b.s=0) ? G: L
    elseif a.t=ZERO and b.t=ZERO then
            c ← E
    else
            assert FALSE // should have covered al the cases above
    endif
enddef

def c ← fmul(a,b) as
    if a.t=NORM and b.t=NORM then
            c.s ← a.s ^ b.s
            c.t ← NORM
            c.e ← a.e + b.e
            c.f ← a.f * b.f
    // priority is given to b operand for NaN propagation
    elseif (b.t=SNAN) or (b.t=QNAN) then
            c.s ← a.s ^ b.s
            c.t ← b.t
            c.e ← b.e
            c.f ← b.f
    elseif (a.t=SNAN) or (a.t=QNAN) then
            c.s ← a.s ^ b.s
            c.t ← a.t
            c.e ← a.e
            c.f ← a.f
    elseif a.t=ZERO and b.t=INFINITY then
            c ← DEFAULTSNAN // Invalid
    elseif a.t=INFINITY and b.t=ZERO then
            c ← DEFAULTSNAN // Invalid
```

Fig. 37 (cont'd)

```
        elseif a.t=ZERO or b.t=ZERO then
                c.s ← a.s ^ b.s
                c.t ← ZERO
        else
                assert FALSE // should have covered al the cases above
        endif
enddef

def c ← fdivr(a,b) as
        if a.t=NORM and b.t=NORM then
                c.s ← a.s ^ b.s
                c.t ← NORM
                c.e ← a.e - b.e + 256
                c.f ← (a.f || 0^256) / b.f
        // priority is given to b operand for NaN propagation
        elseif (b.t=SNAN) or (b.t=QNAN) then
                c.s ← a.s ^ b.s
                c.t ← b.t
                c.e ← b.e
                c.f ← b.f
        elseif (a.t=SNAN) or (a.t=QNAN) then
                c.s ← a.s ^ b.s
                c.t ← a.t
                c.e ← a.e
                c.f ← a.f
        elseif a.t=ZERO and b.t=ZERO then
                c ← DEFAULTSNAN // Invalid
        elseif a.t=INFINITY and b.t=INFINITY then
                c ← DEFAULTSNAN // Invalid
        elseif a.t=ZERO then
                c.s ← a.s ^ b.s
                c.t ← ZERO
        elseif a.t=INFINITY then
                c.s ← a.s ^ b.s
                c.t ← INFINITY
        else
                assert FALSE // should have covered al the cases above
        endif
enddef

def msb ← findmsb(a) as
        MAXF ← 2^18 // Largest possible f value after matrix multiply
        for j ← 0 to MAXF
                if a_MAXF-1..j = (0^(MAXF-1-j) || 1) then
                        msb ← j
                endif
        endfor
enddef

def ai ← PackF(prec,a,round) as
        case a.t of
                NORM:
                        msb ← findmsb(a.f)
                        rn ← msb-1-fbits(prec) // lsb for normal
                        rdn ← -ebias(prec)-a.e-1-fbits(prec) // lsb if a denormal
                        rb ← (rn > rdn) ? rn : rdn
```

Fig. 37 (cont'd)

```
            if rb ≤ 0 then
                aifr ← a.f_{msb-1..0} || 0^{-rb}
                eadj ← 0
            else
                case round of
                    C:
                        s ← 0^{msb-rb} || (~a.s)^{rb}
                    F:
                        s ← 0^{msb-rb} || (a.s)^{rb}
                    N, NONE:
                        s ← 0^{msb-rb} || ~a.f_{rb} || a.f_{rb}^{rb-1}
                    X:
                        if a.f_{rb-1..0} ≠ 0 then
                            raise FloatingPointArithmetic // Inexact
                        endif
                        s ← 0
                    Z:
                        s ← 0
                endcase
                v ← (0||a.f_{msb..0}) + (0||s)
                if v_{msb} = 1 then
                    aifr ← v_{msb-1..rb}
                    eadj ← 0
                else
                    aifr ← 0^{fbits(prec)}
                    eadj ← 1
                endif
            endif
            aien ← a.e + msb – 1 + eadj + ebias(prec)
            if aien ≤ 0 then
                if round = NONE then
                    ai ← a.s || 0^{ebits(prec)} || aifr
                else
                    raise FloatingPointArithmetic //Underflow
                endif
            elseif aien ≥ 1^{ebits(prec)} then
                if round = NONE then
                    //default: round-to-nearest overflow handling
                    ai ← a.s || 1^{ebits(prec)} || 0^{fbits(prec)}
                else
                    raise FloatingPointArithmetic //Underflow
                endif
            else
                ai ← a.s || aien_{ebits(prec)-1..0} || aifr
            endif
        SNAN:
            if round ≠ NONE then
                raise FloatingPointArithmetic //Invalid
            endif
            if –a.e < fbits(prec) then
                ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..0} || 0^{fbits(prec)+a.e}
```

Fig. 37 (cont'd)

```
                else
                        lsb ← a.f_{-a.e-1-fbits(prec)+1..0} ≠ 0
                        ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..-a.e-1-fbits(prec)+2} || lsb
                endif
        QNAN:
                if –a.e < fbits(prec) then
                        ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..0} || 0^{fbits(prec)+a.e}
                else
                        lsb ← a.f_{-a.e-1-fbits(prec)+1..0} ≠ 0
                        ai ← a.s || 1^{ebits(prec)} || a.f_{-a.e-1..-a.e-1-fbits(prec)+2} || lsb
                endif
        ZERO:
                ai ← a.s || 0^{ebits(prec)} || 0^{fbits(prec)}
        INFINITY:
                ai ← a.s || 1^{ebits(prec)} || 0^{fbits(prec)}
    endcase
defdef

def ai ← fsinkr(prec, a, round) as
    case a.t of
        NORM:
            msb ← findmsb(a.f)
            rb ← -a.e
            if rb ≤ 0 then
                aifr ← a.f_{msb..0} || 0^{-rb}
                aims ← msb - rb
            else
                case round of
                    C, C.D:
                        s ← 0^{msb-rb} || (~ai.s)^{rb}
                    F, F.D:
                        s ← 0^{msb-rb} || (ai.s)^{rb}
                    N, NONE:
                        s ← 0^{msb-rb} || ~ai.f_{rb} || ai.f_{rb}^{rb-1}
                    X:
                        if ai.f_{rb-1..0} ≠ 0 then
                            raise FloatingPointArithmetic // Inexact
                        endif
                        s ← 0
                    Z, Z.D:
                        s ← 0
                endcase
                v ← (0||a.f_{msb..0}) + (0||s)
                if v_{msb} = 1 then
                    aims ← msb + 1 - rb
                else
                    aims ← msb - rb
                endif
                aifr ← v_{aims..rb}
            endif
            if aims > prec then
                case round of
                    C.D, F.D, NONE, Z.D:
                        ai ← a.s || (~as)^{prec-1}
```

Fig. 37 (cont'd)

```
                    C, F, N, X, Z:
                        raise FloatingPointArithmetic // Overflow
                endcase
            elseif a.s = 0 then
                ai ← aifr
            else
                ai ← -aifr
            endif
        ZERO:
            ai ← 0^prec
        SNAN, QNAN:
            case round of
                C.D, F.D, NONE, Z.D:
                    ai ← 0^prec
                C, F, N, X, Z:
                    raise FloatingPointArithmetic // Invalid
            endcase
        INFINITY:
            case round of
                C.D, F.D, NONE, Z.D:
                    ai ← a.s || (~as)^prec-1
                C, F, N, X, Z:
                    raise FloatingPointArithmetic // Invalid
            endcase
    endcase
enddef

def c ← frecrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fdiv(b,a))
enddef

def c ← frsqrest(a) as
    b.s ← 0
    b.t ← NORM
    b.e ← 0
    b.f ← 1
    c ← fest(fsqr(fdiv(b,a)))
enddef

def c ← fest(a) as
    if (a.t=NORM) then
        msb ← findmsb(a.f)
        a.e ← a.e + msb - 13
        a.f ← a.f_msb..msb-12 || 1
    else
        c ← a
    endif
enddef

def c ← fsqr(a) as
    if (a.t=NORM) and (a.s=0) then
        c.s ← 0
        c.t ← NORM
        if (a.e_0 = 1) then
```

Fig. 37 (cont'd)

```
            c.e ← (a.e-127) / 2
            c.f ← sqr(a.f || 0^127)
        else
            c.e ← (a.e-128) / 2
            c.f ← sqr(a.f || 0^128)
        endif
    elseif (a.t=SNAN) or (a.t=QNAN) or a.t=ZERO or ((a.t=INFINITY) and (a.s=0)) then
        c ← a
    elseif ((a.t=NORM) or (a.t=INFINITY)) and (a.s=1) then
        c ← DEFAULTSNAN // Invalid
    else
        assert FALSE // should have covered al the cases above
    endif
enddef
```

Fig. 37 (cont'd)

E.ADD.F.16	Ensemble add floating-point half
E.ADD.F.16.C	Ensemble add floating-point half ceiling
E.ADD.F.16.F	Ensemble add floating-point half floor
E.ADD.F.16.N	Ensemble add floating-point half nearest
E.ADD.F.16.X	Ensemble add floating-point half exact
E.ADD.F.16.Z	Ensemble add floating-point half zero
E.ADD.F.32	Ensemble add floating-point single
E.ADD.F.32.C	Ensemble add floating-point single ceiling
E.ADD.F.32.F	Ensemble add floating-point single floor
E.ADD.F.32.N	Ensemble add floating-point single nearest
E.ADD.F.32.X	Ensemble add floating-point single exact
E.ADD.F.32.Z	Ensemble add floating-point single zero
E.ADD.F.64	Ensemble add floating-point double
E.ADD.F.64.C	Ensemble add floating-point double ceiling
E.ADD.F.64.F	Ensemble add floating-point double floor
E.ADD.F.64.N	Ensemble add floating-point double nearest
E.ADD.F.64.X	Ensemble add floating-point double exact
E.ADD.F.64.Z	Ensemble add floating-point double zero
E.ADD.F.128	Ensemble add floating-point quad
E.ADD.F.128.C	Ensemble add floating-point quad ceiling
E.ADD.F.128.F	Ensemble add floating-point quad floor
E.ADD.F.128.N	Ensemble add floating-point quad nearest
E.ADD.F.128.X	Ensemble add floating-point quad exact
E.ADD.F.128.Z	Ensemble add floating-point quad zero
E.DIV.F.16	Ensemble divide floating-point half
E.DIV.F.16.C	Ensemble divide floating-point half ceiling
E.DIV.F.16.F	Ensemble divide floating-point half floor
E.DIV.F.16.N	Ensemble divide floating-point half nearest
E.DIV.F.16.X	Ensemble divide floating-point half exact
E.DIV.F.16.Z	Ensemble divide floating-point half zero
E.DIV.F.32	Ensemble divide floating-point single
E.DIV.F.32.C	Ensemble divide floating-point single ceiling
E.DIV.F.32.F	Ensemble divide floating-point single floor
E.DIV.F.32.N	Ensemble divide floating-point single nearest
E.DIV.F.32.X	Ensemble divide floating-point single exact
E.DIV.F.32.Z	Ensemble divide floating-point single zero
E.DIV.F.64	Ensemble divide floating-point double

Fig. 38A

E.DIV.F.64.C	Ensemble divide floating-point double ceiling
E.DIV.F.64.F	Ensemble divide floating-point double floor
E.DIV.F.64.N	Ensemble divide floating-point double nearest
E.DIV.F.64.X	Ensemble divide floating-point double exact
E.DIV.F.64.Z	Ensemble divide floating-point double zero
E.DIV.F.128	Ensemble divide floating-point quad
E.DIV.F.128.C	Ensemble divide floating-point quad ceiling
E.DIV.F.128.F	Ensemble divide floating-point quad floor
E.DIV.F.128.N	Ensemble divide floating-point quad nearest
E.DIV.F.128.X	Ensemble divide floating-point quad exact
E.DIV.F.128.Z	Ensemble divide floating-point quad zero
E.MUL.C.F.16	Ensemble multiply complex floating-point half
E.MUL.C.F.32	Ensemble multiply complex floating-point single
E.MUL.C.F.64	Ensemble multiply complex floating-point double
E.MUL.F.16	Ensemble multiply floating-point half
E.MUL.F.16.C	Ensemble multiply floating-point half ceiling
E.MUL.F.16.F	Ensemble multiply floating-point half floor
E.MUL.F.16.N	Ensemble multiply floating-point half nearest
E.MUL.F.16.X	Ensemble multiply floating-point half exact
E.MUL.F.16.Z	Ensemble multiply floating-point half zero
E.MUL.F.32	Ensemble multiply floating-point single
E.MUL.F.32.C	Ensemble multiply floating-point single ceiling
E.MUL.F.32.F	Ensemble multiply floating-point single floor
E.MUL.F.32.N	Ensemble multiply floating-point single nearest
E.MUL.F.32.X	Ensemble multiply floating-point single exact
E.MUL.F.32.Z	Ensemble multiply floating-point single zero
E.MUL.F.64	Ensemble multiply floating-point double
E.MUL.F.64.C	Ensemble multiply floating-point double ceiling
E.MUL.F.64.F	Ensemble multiply floating-point double floor
E.MUL.F.64.N	Ensemble multiply floating-point double nearest
E.MUL.F.64.X	Ensemble multiply floating-point double exact
E.MUL.F.64.Z	Ensemble multiply floating-point double zero
E.MUL.F.128	Ensemble multiply floating-point quad
E.MUL.F.128.C	Ensemble multiply floating-point quad ceiling
E.MUL.F.128.F	Ensemble multiply floating-point quad floor
E.MUL.F.128.N	Ensemble multiply floating-point quad nearest
E.MUL.F.128.X	Ensemble multiply floating-point quad exact
E.MUL.F.128.Z	Ensemble multiply floating-point quad zero

Fig. 38A (cont'd)

Selection

class	op	prec	round/trap
add	EADDF	16 32 64 128	NONE C F N X Z
divide	EDIVF	16 32 64 128	NONE C F N X Z
multiply	EMULF	16 32 64 128	NONE C F N X Z
complex multiply	EMUL.C F	16 32 64	NONE

Format

E.op.prec.round rd=rc,rb

rd=eopprecround(rc,rb)

31 24	23 18	17 12	11 6	5 0
E.prec	**rd**	**rc**	**rb**	**op.round**
8	6	6	6	6

Fig. 38B

Definition

```
def mul(size,v,i,w,j) as
	mul ← fmul(F(size,v_{size-1+i..i}),F(size,w_{size-1+j..j}))
enddef

def EnsembleFloatingPoint(op,prec,round,ra,rb,rc) as
	c ← RegRead(rc, 128)
	b ← RegRead(rb, 128)
	for i ← 0 to 128-prec by prec
		ci ← F(prec,c_{i+prec-1..i})
		bi ← F(prec,b_{i+prec-1..i})
		case op of
			E.ADD.F:
				ai ← faddr(ci,bi,round)
			E.MUL.F:
				ai ← fmul(ci,bi)
			E.MUL.C.F:
				if (i and prec) then
					ai ← fadd(mul(prec,c,i,b,i-prec), mul(prec,c,i-prec,b,i))
				else
					ai ← fsub(mul(prec,c,I,b,I), mul(prec,c,i+prec,b,i+prec))
				endif
			E.DIV.F.:
				ai ← fdiv(ci,bi)
		endcase
		a_{i+prec-1..i} ← PackF(prec, ai, round)
	endfor
	RegWrite(rd, 128, a)
enddef
```

Exceptions

Floating-point arithmetic

Fig. 38C

Operation codes

E.MUL.ADD.C.F.16	Ensemble multiply add complex floating-point half
E.MUL.ADD.C.F.32	Ensemble multiply add complex floating-point single
E.MUL.ADD.C.F.64	Ensemble multiply add complex floating-point double
E.MUL.ADD.F.16	Ensemble multiply add floating-point half
E.MUL.ADD.F.16.C	Ensemble multiply add floating-point half ceiling
E.MUL.ADD.F.16.F	Ensemble multiply add floating-point half floor
E.MUL.ADD.F.16.N	Ensemble multiply add floating-point half nearest
E.MUL.ADD.F.16.X	Ensemble multiply add floating-point half exact
E.MUL.ADD.F.16.Z	Ensemble multiply add floating-point half zero
E.MUL.ADD.F.32	Ensemble multiply add floating-point single
E.MUL.ADD.F.32.C	Ensemble multiply add floating-point single ceiling
E.MUL.ADD.F.32.F	Ensemble multiply add floating-point single floor
E.MUL.ADD.F.32.N	Ensemble multiply add floating-point single nearest
E.MUL.ADD.F.32.X	Ensemble multiply add floating-point single exact
E.MUL.ADD.F.32.Z	Ensemble multiply add floating-point single zero
E.MUL.ADD.F.64	Ensemble multiply add floating-point double
E.MUL.ADD.F.64.C	Ensemble multiply add floating-point double ceiling
E.MUL.ADD.F.64.F	Ensemble multiply add floating-point double floor
E.MUL.ADD.F.64.N	Ensemble multiply add floating-point double nearest
E.MUL.ADD.F.64.X	Ensemble multiply add floating-point double exact
E.MUL.ADD.F.64.Z	Ensemble multiply add floating-point double zero
E.MUL.ADD.F.128	Ensemble multiply add floating-point quad
E.MUL.ADD.F.128.C	Ensemble multiply add floating-point quad ceiling
E.MUL.ADD.F.128.F	Ensemble multiply add floating-point quad floor
E.MUL.ADD.F.128.N	Ensemble multiply add floating-point quad nearest
E.MUL.ADD.F.128.X	Ensemble multiply add floating-point quad exact
E.MUL.ADD.F.128.Z	Ensemble multiply add floating-point quad zero
E.MUL.SUB.C.F.16	Ensemble multiply subtract complex floating-point half
E.MUL.SUB.C.F.32	Ensemble multiply subtract complex floating-point single
E.MUL.SUB.C.F.64	Ensemble multiply subtract complex floating-point double
E.MUL.SUB.F.16	Ensemble multiply subtract floating-point half
E.MUL.SUB.F.32	Ensemble multiply subtract floating-point single
E.MUL.SUB.F.64	Ensemble multiply subtract floating-point double
E.MUL.SUB.F.128	Ensemble multiply subtract floating-point quad

Fig. 38D

Selection

class	op	type	prec	round/trap
multiply add	E.MUL.ADD	F	16 32 64 128	NONE C F N X Z
		C.F	16 32 64	NONE
multiply subtract	E.MUL.SUB	F	16 32 64 128	NONE
		C.F	16 32 64	NONE

Format

E.op.size rd@rc,rb

rd=eopsize(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
E.size	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

Fig. 38E

Definition

```
def mul(size,v,i,w,j) as
    mul ← fmul(F(size,v_{size-1+i..i}),F(size,w_{size-1+j..j}))
enddef

def EnsembleInplaceFloatingPoint(op,size,rd,rc,rb) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-size by size
        di ← F(prec,d_{i+prec-1..i})
        case op of
            E.MUL.ADD.F:
                ai ← fadd(di, mul(prec,c,i,b,i))
            E.MUL.ADD.C.F:
                if (i and prec) then
                    ai ← fadd(di, fadd(mul(prec,c,i,b,i-prec), mul(c,i-prec,b,i)))
                else
                    ai ← fadd(di, fsub(mul(prec,c,i,b,i), mul(prec,c,i+prec,b,i+prec)))
                endif
            E.MUL.SUB.F:
                ai ← frsub(di, mul(prec,c,i,b,i))
            E.MUL.SUB.C.F:
                if (i and prec) then
                    ai ← frsub(di, fadd(mul(prec,c,i,b,i-prec), mul(c,i-prec,b,i)))
                else
                    ai ← frsub(di, fsub(mul(prec,c,i,b,i), mul(prec,c,i+prec,b,i+prec)))
                endif
        endcase
        a_{i+prec-1..i} ← PackF(prec, ai, round)
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig. 38F

Operation codes

E.SCAL.ADD.F.16	Ensemble scale add floating-point half
E.SCAL.ADD.F.32	Ensemble scale add floating-point single
E.SCAL.ADD.F.64	Ensemble scale add floating-point double

Fig. 38G

Selection

class	op	prec
scale add	E.SCAL.ADD.F	16 32 64

Format

E.SCAL.ADD.F.size ra=rd,rc,rb

ra=escaladdfsize(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 38H

Definition

```
def EnsembleFloatingPointTernary(op,prec,rd,rc,rb,ra) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-prec by prec
        di ← F(prec,d_{i+prec-1..i})
        ci ← F(prec,c_{i+prec-1..i})
        ai ← fadd(fmul(di, F(prec,b_{prec-1..0})), fmul(ci, F(prec,b_{2*prec-1..prec})))
        a_{i+prec-1..i} ← PackF(prec, ai, none)
    endfor
    RegWrite(ra, 128, a)
enddef
```

Exceptions

none

Fig. 38I

E.SUB.F.16	Ensemble subtract floating-point half
E.SUB.F.16.C	Ensemble subtract floating-point half ceiling
E.SUB.F.16.F	Ensemble subtract floating-point half floor
E.SUB.F.16.N	Ensemble subtract floating-point half nearest
E.SUB.F.16.Z	Ensemble subtract floating-point half zero
E.SUB.F.16.X	Ensemble subtract floating-point half exact
E.SUB.F.32	Ensemble subtract floating-point single
E.SUB.F.32.C	Ensemble subtract floating-point single ceiling
E.SUB.F.32.F	Ensemble subtract floating-point single floor
E.SUB.F.32.N	Ensemble subtract floating-point single nearest
E.SUB.F.32.Z	Ensemble subtract floating-point single zero
E.SUB.F.32.X	Ensemble subtract floating-point single exact
E.SUB.F.64	Ensemble subtract floating-point double
E.SUB.F.64.C	Ensemble subtract floating-point double ceiling
E.SUB.F.64.F	Ensemble subtract floating-point double floor
E.SUB.F.64.N	Ensemble subtract floating-point double nearest
E.SUB.F.64.Z	Ensemble subtract floating-point double zero
E.SUB.F.64.X	Ensemble subtract floating-point double exact
E.SUB.F.128	Ensemble subtract floating-point quad
E.SUB.F.128.C	Ensemble subtract floating-point quad ceiling
E.SUB.F.128.F	Ensemble subtract floating-point quad floor
E.SUB.F.128.N	Ensemble subtract floating-point quad nearest
E.SUB.F.128.Z	Ensemble subtract floating-point quad zero
E.SUB.F.128.X	Ensemble subtract floating-point quad exact

Fig. 39A

Selection

class	op	prec	round/trap
set	SET. E LG L GE	16 32 64 128	NONE X
subtract	SUB	16 32 64 128	NONE C F N X Z

Format

E.op.prec.round rd=rb,rc

rd=eopprecround(rb,rc)

31 24	23 18	17 12	11 6	5 0
E.prec	**rd**	**rc**	**rb**	**op.round**
8	6	6	6	6

Fig. 39B

Definition

```
def EnsembleReversedFloatingPoint(op,prec,round,rd,rc,rb) as
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-prec by prec
        ci ← F(prec,c_{i+prec-1..i})
        bi ← F(prec,b_{i+prec-1..i})
        ai ← frsubr(ci,-bi, round)
        a_{i+prec-1..i} ← PackF(prec, ai, round)
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Floating-point arithmetic

Fig. 39C

Operation codes

G.SET.E.F.16	Group set equal floating-point half
G.SET.E.F.16.X	Group set equal floating-point half exact
G.SET.E.F.32	Group set equal floating-point single
G.SET.E.F.32.X	Group set equal floating-point single exact
G.SET.E.F.64	Group set equal floating-point double
G.SET.E.F.64.X	Group set equal floating-point double exact
G.SET.E.F.128	Group set equal floating-point quad
G.SET.E.F.128.X	Group set equal floating-point quad exact
G.SET.GE.F.16.X	Group set greater equal floating-point half exact
G.SET.GE.F.32.X	Group set greater equal floating-point single exact
G.SET.GE.F.64.X	Group set greater equal floating-point double exact
G.SET.GE.F.128.X	Group set greater equal floating-point quad exact
G.SET.LG.F.16	Group set less greater floating-point half
G.SET.LG.F.16.X	Group set less greater floating-point half exact
G.SET.LG.F.32	Group set less greater floating-point single
G.SET.LG.F.32.X	Group set less greater floating-point single exact
G.SET.LG.F.64	Group set less greater floating-point double
G.SET.LG.F.64.X	Group set less greater floating-point double exact
G.SET.LG.F.128	Group set less greater floating-point quad
G.SET.LG.F.128.X	Group set less greater floating-point quad exact
G.SET.L.F.16	Group set less floating-point half
G.SET.L.F.16.X	Group set less floating-point half exact
G.SET.L.F.32	Group set less floating-point single
G.SET.L.F.32.X	Group set less floating-point single exact
G.SET.L.F.64	Group set less floating-point double
G.SET.L.F.64.X	Group set less floating-point double exact
G.SET.L.F.128	Group set less floating-point quad
G.SET.L.F.128.X	Group set less floating-point quad exact
G.SET.GE.F.16	Group set greater equal floating-point half
G.SET.GE.F.32	Group set greater equal floating-point single
G.SET.GE.F.64	Group set greater equal floating-point double
G.SET.GE.F.128	Group set greater equal floating-point quad

Fig. 39D

Equivalencies

G.SET.LE.F.16.X	Group set less equal floating-point half exact
G.SET.LE.F.32.X	Group set less equal floating-point single exact
G.SET.LE.F.64.X	Group set less equal floating-point double exact
G.SET.LE.F.128.X	Group set less equal floating-point quad exact
G.SET.G.F.16	Group set greater floating-point half
G.SET.G.F.16.X	Group set greater floating-point half exact
G.SET.G.F.32	Group set greater floating-point single
G.SET.G.F.32.X	Group set greater floating-point single exact
G.SET.G.F.64	Group set greater floating-point double
G.SET.G.F.64.X	Group set greater floating-point double exact
G.SET.G.F.128	Group set greater floating-point quad
G.SET.G.F.128.X	Group set greater floating-point quad exact
G.SET.LE.F.16	Group set less equal floating-point half
G.SET.LE.F.32	Group set less equal floating-point single
G.SET.LE.F.64	Group set less equal floating-point double
G.SET.LE.F.128	Group set less equal floating-point quad

G.SET.G.F.prec rd=rb,rc	→	G.SET.L.F.prec rd=rc,rb
G.SET.G.F.prec.X rd=rb,rc	→	G.SET.L.F.prec.X rd=rc,rb
G.SET.LE.F.prec rd=rb,rc	→	G.SET.GE.F.prec rd=rc,rb
G.SET.LE.F.prec.X rd=rb,rc	→	G.SET.GE.F.prec.X rd=rc,rb

Fig. 39E

Selection

class	op	prec	round/trap
set	SET. E LG L GE *G* *LE*	16 32 64 128	NONE X

Format

G.op.prec.round   rd=rb,rc

rc=gopprecround(rb,ra)

31 24	23 18	17 12	11 6	5 0
G.prec	**rd**	**rc**	**rb**	**op.round**
8	6	6	6	6

Fig 39F

Definition

```
def GroupFloatingPointReversed(op,prec,round,rd,rc,rb) as
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    for i ← 0 to 128-prec by prec
        ci ← F(prec,c_{i+prec-1..i})
        bi ← F(prec,b_{i+prec-1..i})
        if round≠NONE then
            if (di.t = SNAN) or (ci.t = SNAN) then
                raise FloatingPointArithmetic
            endif
            case op of
                G.SET.L.F, G.SET.GE.F:
                    if (di.t = QNAN) or (ci.t = QNAN) then
                        raise FloatingPointArithmetic
                    endif
                others: //nothing
            endcase
        endif
        case op of
            G.SET.L.F:
                ai ← bi?≥ci
            G.SET.GE.F:
                ai ← bi!?<ci
            G.SET.E.F:
                ai ← bi=ci
            G.SET.LG.F:
                ai ← bi≠ci
        endcase
        a_{i+prec-1..i} ← ai^prec
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Floating-point arithmetic

Fig. 39G

G.COM.E.F.16	Group compare equal floating-point half
G.COM.E.F.16.X	Group compare equal floating-point half exact
G.COM.E.F.32	Group compare equal floating-point single
G.COM.E.F.32.X	Group compare equal floating-point single exact
G.COM.E.F.64	Group compare equal floating-point double
G.COM.E.F.64.X	Group compare equal floating-point double exact
G.COM.E.F.128	Group compare equal floating-point quad
G.COM.E.F.128.X	Group compare equal floating-point quad exact
G.COM.GE.F.16	Group compare greater or equal floating-point half
G.COM.GE.F.16.X	Group compare greater or equal floating-point half exact
G.COM.GE.F.32	Group compare greater or equal floating-point single
G.COM.GE.F.32.X	Group compare greater or equal floating-point single exact
G.COM.GE.F.64	Group compare greater or equal floating-point double
G.COM.GE.F.64.X	Group compare greater or equal floating-point double exact
G.COM.GE.F.128	Group compare greater or equal floating-point quad
G.COM.GE.F.128.X	Group compare greater or equal floating-point quad exact
G.COM.L.F.16	Group compare less floating-point half
G.COM.L.F.16.X	Group compare less floating-point half exact
G.COM.L.F.32	Group compare less floating-point single
G.COM.L.F.32.X	Group compare less floating-point single exact
G.COM.L.F.64	Group compare less floating-point double
G.COM.L.F.64.X	Group compare less floating-point double exact
G.COM.L.F.128	Group compare less floating-point quad
G.COM.L.F.128.X	Group compare less floating-point quad exact
G.COM.LG.F.16	Group compare less or greater floating-point half
G.COM.LG.F.16.X	Group compare less or greater floating-point half exact
G.COM.LG.F.32	Group compare less or greater floating-point single
G.COM.LG.F.32.X	Group compare less or greater floating-point single exact
G.COM.LG.F.64	Group compare less or greater floating-point double
G.COM.LG.F.64.X	Group compare less or greater floating-point double exact
G.COM.LG.F.128	Group compare less or greater floating-point quad
G.COM.LG.F.128.X	Group compare less or greater floating-point quad exact

Fig. 40A

Format

G.COM.op.prec.round rd,rc

rc=gcomopprecround(rd,rc)

31 24	23 18	17 12	11 6	5 0
G.prec	**rd**	**rc**	**op**	**GCOM**
8	6	6	6	6

Fig. 40B

Definition

```
def GroupCompareFloatingPoint(op,prec,round,rd,rc) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    for i ← 0 to 128-prec by prec
        di ← F(prec,d_{i+prec-1..i})
        ci ← F(prec,c_{i+prec-1..i})
        if round≠NONE then
            if (di.t = SNAN) or (ci.t = SNAN) then
                raise FloatingPointArithmetic
            endif
            case op of
                G.COM.L.F, G.COM.GE.F:
                    if (di.t = QNAN) or (ci.t = QNAN) then
                        raise FloatingPointArithmetic
                    endif
                others: //nothing
            endcase
        endif
        case op of
            G.COM.L.F:
                ai ← di?≥ci
            G.COM.GE.F:
                ai ← di!?<ci
            G.COM.E.F:
                ai ← di=ci
            G.COM.LG.F:
                ai ← di≠ci
        endcase
        a_{i+prec-1..i} ← ai
    endfor
    if (a ≠ 0) then
        raise FloatingPointArithmetic
    endif
enddef
```

Exceptions

Floating-point arithmetic

Fig. 40C

E.ABS.F.16	Ensemble absolute value floating-point half
E.ABS.F.16.X	Ensemble absolute value floating-point half exception
E.ABS.F.32	Ensemble absolute value floating-point single
E.ABS.F.32.X	Ensemble absolute value floating-point single exception
E.ABS.F.64	Ensemble absolute value floating-point double
E.ABS.F.64.X	Ensemble absolute value floating-point double exception
E.ABS.F.128	Ensemble absolute value floating-point quad
E.ABS.F.128.X	Ensemble absolute value floating-point quad exception
E.COPY.F.16	Ensemble copy floating-point half
E.COPY.F.16.X	Ensemble copy floating-point half exception
E.COPY.F.32	Ensemble copy floating-point single
E.COPY.F.32.X	Ensemble copy floating-point single exception
E.COPY.F.64	Ensemble copy floating-point double
E.COPY.F.64.X	Ensemble copy floating-point double exception
E.COPY.F.128	Ensemble copy floating-point quad
E.COPY.F.128.X	Ensemble copy floating-point quad exception
E.DEFLATE.F.32	Ensemble convert floating-point half from single
E.DEFLATE.F.32.C	Ensemble convert floating-point half from single ceiling
E.DEFLATE.F.32.F	Ensemble convert floating-point half from single floor
E.DEFLATE.F.32.N	Ensemble convert floating-point half from single nearest
E.DEFLATE.F.32.X	Ensemble convert floating-point half from single exact
E.DEFLATE.F.32.Z	Ensemble convert floating-point half from single zero
E.DEFLATE.F.64	Ensemble convert floating-point single from double
E.DEFLATE.F.64.C	Ensemble convert floating-point single from double ceiling
E.DEFLATE.F.64.F	Ensemble convert floating-point single from double floor
E.DEFLATE.F.64.N	Ensemble convert floating-point single from double nearest
E.DEFLATE.F.64.X	Ensemble convert floating-point single from double exact
E.DEFLATE.F.64.Z	Ensemble convert floating-point single from double zero
E.DEFLATE.F.128	Ensemble convert floating-point double from quad
E.DEFLATE.F.128.C	Ensemble convert floating-point double from quad ceiling
E.DEFLATE.F.128.F	Ensemble convert floating-point double from quad floor
E.DEFLATE.F.128.N	Ensemble convert floating-point double from quad nearest
E.DEFLATE.F.128.X	Ensemble convert floating-point double from quad exact
E.DEFLATE.F.128.Z	Ensemble convert floating-point double from quad zero
E.FLOAT.F.16	Ensemble convert floating-point half from doublets
E.FLOAT.F.16.C	Ensemble convert floating-point half from doublets ceiling
E.FLOAT.F.16.F	Ensemble convert floating-point half from doublets floor
E.FLOAT.F.16.N	Ensemble convert floating-point half from doublets nearest
E.FLOAT.F.16.X	Ensemble convert floating-point half from doublets exact
E.FLOAT.F.16.Z	Ensemble convert floating-point half from doublets zero

Fig. 41A

E.FLOAT.F.32	Ensemble convert floating-point single from quadlets
E.FLOAT.F.32.C	Ensemble convert floating-point single from quadlets ceiling
E.FLOAT.F.32.F	Ensemble convert floating-point single from quadlets floor
E.FLOAT.F.32.N	Ensemble convert floating-point single from quadlets nearest
E.FLOAT.F.32.X	Ensemble convert floating-point single from quadlets exact
E.FLOAT.F.32.Z	Ensemble convert floating-point single from quadlets zero
E.FLOAT.F.64	Ensemble convert floating-point double from octlets
E.FLOAT.F.64.C	Ensemble convert floating-point double from octlets ceiling
E.FLOAT.F.64.F	Ensemble convert floating-point double from octlets floor
E.FLOAT.F.64.N	Ensemble convert floating-point double from octlets nearest
E.FLOAT.F.64.X	Ensemble convert floating-point double from octlets exact
E.FLOAT.F.64.Z	Ensemble convert floating-point double from octlets zero
E.FLOAT.F.128	Ensemble convert floating-point quad from hexlet
E.FLOAT.F.128.C	Ensemble convert floating-point quad from hexlet ceiling
E.FLOAT.F.128.F	Ensemble convert floating-point quad from hexlet floor
E.FLOAT.F.128.N	Ensemble convert floating-point quad from hexlet nearest
E.FLOAT.F.128.X	Ensemble convert floating-point quad from hexlet exact
E.FLOAT.F.128.Z	Ensemble convert floating-point quad from hexlet zero
E.INFLATE.F.16	Ensemble convert floating-point single from half
E.INFLATE.F.16.X	Ensemble convert floating-point single from half exception
E.INFLATE.F.32	Ensemble convert floating-point double from single
E.INFLATE.F.32.X	Ensemble convert floating-point double from single exception
E.INFLATE.F.64	Ensemble convert floating-point quad from double
E.INFLATE.F.64.X	Ensemble convert floating-point quad from double exception
E.NEG.F.16	Ensemble negate floating-point half
E.NEG.F.16.X	Ensemble negate floating-point half exception
E.NEG.F.32	Ensemble negate floating-point single
E.NEG.F.32.X	Ensemble negate floating-point single exception
E.NEG.F.64	Ensemble negate floating-point double
E.NEG.F.64.X	Ensemble negate floating-point double exception
E.NEG.F.128	Ensemble negate floating-point quad
E.NEG.F.128.X	Ensemble negate floating-point quad exception
E.RECEST.F.16	Ensemble reciprocal estimate floating-point half
E.RECEST.F.16.X	Ensemble reciprocal estimate floating-point half exception
E.RECEST.F.32	Ensemble reciprocal estimate floating-point single
E.RECEST.F.32.X	Ensemble reciprocal estimate floating-point single exception
E.RECEST.F.64	Ensemble reciprocal estimate floating-point double
E.RECEST.F.64.X	Ensemble reciprocal estimate floating-point double exception
E.RECEST.F.128	Ensemble reciprocal estimate floating-point quad
E.RECEST.F.128.X	Ensemble reciprocal estimate floating-point quad exception

Fig. 41A (cont'd)

E.RSQREST.F.16	Ensemble floating-point reciprocal square root estimate half
E.RSQREST.F.16.X	Ensemble floating-point reciprocal square root estimate half exact
E.RSQREST.F.32	Ensemble floating-point reciprocal square root estimate single
E.RSQREST.F.32.X	Ensemble floating-point reciprocal square root estimate single exact
E.RSQREST.F.64	Ensemble floating-point reciprocal square root estimate double
E.RSQREST.F.64.X	Ensemble floating-point reciprocal square root estimate double exact
E.RSQREST.F.128	Ensemble floating-point reciprocal square root estimate quad
E.RSQREST.F.128.X	Ensemble floating-point reciprocal square root estimate quad exact
E.SINK.F.16	Ensemble convert floating-point doublets from half nearest default
E.SINK.F.16.C	Ensemble convert floating-point doublets from half ceiling
E.SINK.F.16.C.D	Ensemble convert floating-point doublets from half ceiling default
E.SINK.F.16.F	Ensemble convert floating-point doublets from half floor
E.SINK.F.16.F.D	Ensemble convert floating-point doublets from half floor default
E.SINK.F.16.N	Ensemble convert floating-point doublets from half nearest
E.SINK.F.16.X	Ensemble convert floating-point doublets from half exact
E.SINK.F.16.Z	Ensemble convert floating-point doublets from half zero
E.SINK.F.16.Z.D	Ensemble convert floating-point doublets from half zero default
E.SINK.F.32	Ensemble convert floating-point quadlets from single nearest default
E.SINK.F.32.C	Ensemble convert floating-point quadlets from single ceiling
E.SINK.F.32.C.D	Ensemble convert floating-point quadlets from single ceiling default
E.SINK.F.32.F	Ensemble convert floating-point quadlets from single floor
E.SINK.F.32.F.D	Ensemble convert floating-point quadlets from single floor default
E.SINK.F.32.N	Ensemble convert floating-point quadlets from single nearest
E.SINK.F.32.X	Ensemble convert floating-point quadlets from single exact
E.SINK.F.32.Z	Ensemble convert floating-point quadlets from single zero
E.SINK.F.32.Z.D	Ensemble convert floating-point quadlets from single zero default
E.SINK.F.64	Ensemble convert floating-point octlets from double nearest default
E.SINK.F.64.C	Ensemble convert floating-point octlets from double ceiling
E.SINK.F.64.C.D	Ensemble convert floating-point octlets from double ceiling default
E.SINK.F.64.F	Ensemble convert floating-point octlets from double floor
E.SINK.F.64.F.D	Ensemble convert floating-point octlets from double floor default
E.SINK.F.64.N	Ensemble convert floating-point octlets from double nearest
E.SINK.F.64.X	Ensemble convert floating-point octlets from double exact
E.SINK.F.64.Z	Ensemble convert floating-point octlets from double zero
E.SINK.F.64.Z.D	Ensemble convert floating-point octlets from double zero default
E.SINK.F.128	Ensemble convert floating-point hexlet from quad nearest default
E.SINK.F.128.C	Ensemble convert floating-point hexlet from quad ceiling
E.SINK.F.128.C.D	Ensemble convert floating-point hexlet from quad ceiling default
E.SINK.F.128.F	Ensemble convert floating-point hexlet from quad floor
E.SINK.F.128.F.D	Ensemble convert floating-point hexlet from quad floor default

Fig. 41A (cont'd)

E.SINK.F.128.N	Ensemble convert floating-point hexlet from quad nearest
E.SINK.F.128.X	Ensemble convert floating-point hexlet from quad exact
E.SINK.F.128.Z	Ensemble convert floating-point hexlet from quad zero
E.SINK.F.128.Z.D	Ensemble convert floating-point hexlet from quad zero default
E.SQR.F.16	Ensemble square root floating-point half
E.SQR.F.16.C	Ensemble square root floating-point half ceiling
E.SQR.F.16.F	Ensemble square root floating-point half floor
E.SQR.F.16.N	Ensemble square root floating-point half nearest
E.SQR.F.16.X	Ensemble square root floating-point half exact
E.SQR.F.16.Z	Ensemble square root floating-point half zero
E.SQR.F.32	Ensemble square root floating-point single
E.SQR.F.32.C	Ensemble square root floating-point single ceiling
E.SQR.F.32.F	Ensemble square root floating-point single floor
E.SQR.F.32.N	Ensemble square root floating-point single nearest
E.SQR.F.32.X	Ensemble square root floating-point single exact
E.SQR.F.32.Z	Ensemble square root floating-point single zero
E.SQR.F.64	Ensemble square root floating-point double
E.SQR.F.64.C	Ensemble square root floating-point double ceiling
E.SQR.F.64.F	Ensemble square root floating-point double floor
E.SQR.F.64.N	Ensemble square root floating-point double nearest
E.SQR.F.64.X	Ensemble square root floating-point double exact
E.SQR.F.64.Z	Ensemble square root floating-point double zero
E.SQR.F.128	Ensemble square root floating-point quad
E.SQR.F.128.C	Ensemble square root floating-point quad ceiling
E.SQR.F.128.F	Ensemble square root floating-point quad floor
E.SQR.F.128.N	Ensemble square root floating-point quad nearest
E.SQR.F.128.X	Ensemble square root floating-point quad exact
E.SQR.F.128.Z	Ensemble square root floating-point quad zero
E.SUM.F.16	Ensemble sum floating-point half
E.SUM.F.16.C	Ensemble sum floating-point half ceiling
E.SUM.F.16.F	Ensemble sum floating-point half floor
E.SUM.F.16.N	Ensemble sum floating-point half nearest
E.SUM.F.16.X	Ensemble sum floating-point half exact
E.SUM.F.16.Z	Ensemble sum floating-point half zero
E.SUM.F.32	Ensemble sum floating-point single
E.SUM.F.32.C	Ensemble sum floating-point single ceiling
E.SUM.F.32.F	Ensemble sum floating-point single floor
E.SUM.F.32.N	Ensemble sum floating-point single nearest
E.SUM.F.32.X	Ensemble sum floating-point single exact
E.SUM.F.32.Z	Ensemble sum floating-point single zero

Fig. 41A (cont'd)

E.SUM.F.64	Ensemble sum floating-point double
E.SUM.F.64.C	Ensemble sum floating-point double ceiling
E.SUM.F.64.F	Ensemble sum floating-point double floor
E.SUM.F.64.N	Ensemble sum floating-point double nearest
E.SUM.F.64.X	Ensemble sum floating-point double exact
E.SUM.F.64.Z	Ensemble sum floating-point double zero
E.SUM.F.128	Ensemble sum floating-point quad
E.SUM.F.128.C	Ensemble sum floating-point quad ceiling
E.SUM.F.128.F	Ensemble sum floating-point quad floor
E.SUM.F.128.N	Ensemble sum floating-point quad nearest
E.SUM.F.128.X	Ensemble sum floating-point quad exact
E.SUM.F.128.Z	Ensemble sum floating-point quad zero

Selection

	op	prec				round/trap
copy	COPY	16	32	64	128	NONE X
absolute value	ABS	16	32	64	128	NONE X
float from integer	FLOAT	16	32	64	128	NONE C F N X Z
integer from float	SINK	16	32	64	128	NONE C F N X Z C.D F.D Z.D
increase format precision	INFLATE	16	32	64		NONE X
decrease format precision	DEFLATE		32	64	128	NONE C F N X Z
negate	NEG	16	32	64	128	NONE X
reciprocal estimate	RECEST	16	32	64	128	NONE X
reciprocal square root estimate	RSQREST	16	32	64	128	NONE X
square root	SQR	16	32	64	128	NONE C F N X Z
sum	SUM	16	32	64	128	NONE C F N X Z

Fig. 41A (cont'd)

Format

E.op.prec.round rd=rc

rd=eopprecround(rc)

31 24	23 18	17 12	11 6	5 0
E.prec	**rd**	**rc**	**op**	**E.UNARY**
8	6	6	6	6

Fig. 41B

Definition

```
def EnsembleUnaryFloatingPoint(op,prec,round,rd,rc) as
    c ← RegRead(rc, 128)
    case op of
        E.ABS.F, E.NEG.F, E.SQR.F:
            for i ← 0 to 128-prec by prec
                ci ← F(prec,c_{i+prec-1..i})
                case op of
                    E.ABS.F:
                        ai.t ← ci.t
                        ai.s ← 0
                        ai.e ← ci.e
                        ai.f ← ci.f
                    E.COPY.F:
                        ai ← ci
                    E.NEG.F:
                        ai.t ← ci.t
                        ai.s ← ~ci.s
                        ai.e ← ci.e
                        ai.f ← ci.f
                    E.RECEST.F:
                        ai ← frecest(ci)
                    E.RSQREST.F:
                        ai ← frsqrest(ci)
                    E.SQR.F:
                        ai ← fsqr(ci)
                endcase
                a_{i+prec-1..i} ← PackF(prec, ai, round)
            endfor
        E.SUM.F:
            p[0].t ← NULL
            for i ← 0 to 128-prec by prec
                p[i+prec] ← fadd(p[i], F(prec,c_{i+prec-1..i}))
            endfor
            a ← PackF(prec, p[128], round)
        E.SINK.F:
            for i ← 0 to 128-prec by prec
                ci ← F(prec,c_{i+prec-1..i})
                a_{i+prec-1..i} ← fsinkr(prec, ci, round)
            endfor
        E.FLOAT.F:
            for i ← 0 to 128-prec by prec
                ci.t ← NORM
                ci.e ← 0
                ci.s ← c_{i+prec-1}
                ci.f ← ci.s ? 1+~c_{i+prec-2..i} : c_{i+prec-2..i}
                a_{i+prec-1..i} ← PackF(prec, ci, round)
            endfor
```

Fig. 41C

```
        E.INFLATE.F:
            for i ← 0 to 64-prec by prec
                ci ← F(prec,c_{i+prec-1..i})
                a_{i+i+prec+prec-1..i+i} ← PackF(prec+prec, ci, round)
            endfor
        E.DEFLATE.F:
            for i ← 0 to 128-prec by prec
                ci ← F(prec,c_{i+prec-1..i})
                a_{i/2+prec/2-1..i/2} ← PackF(prec/2, ci, round)
            endfor
            a_{127..64} ← 0
    endcase
    RegWrite[rd, 128, a]
enddef
```

Exceptions

Floating-point arithmetic

Fig. 41C (cont'd)

E.MUL.G.8	Ensemble multiply Galois field byte
E.MUL.G.64	Ensemble multiply Galois field octlet

Fig. 42A

Format

E.MUL.G.size   ra=rd,rc,rb

ra=emulgsize(rd,rc,rb)

31 … 24	23 … 18	17 … 12	11 … 6	5 … 0
E.MUL.G.size	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig.42B

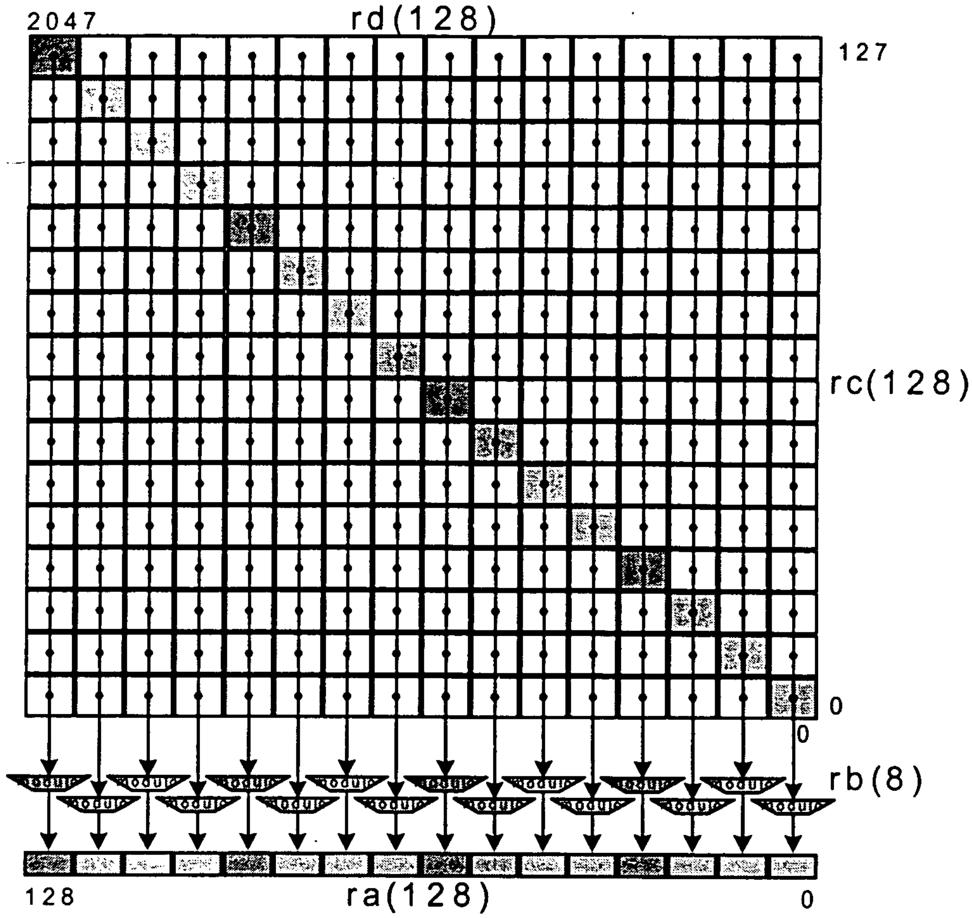
Definition

```
def c ← PolyMultiply(size,a,b) as
	p[0] ← 0^(2*size)
	for k ← 0 to size-1
		p[k+1] ← p[k] ^ a_k ? (0^(size-k) || b || 0^k) : 0^(2*size)
	endfor
	c ← p[size]
enddef

def c ← PolyResidue(size,a,b) as
	p[0] ← a
	for k ← size-1 to 0 by -1
		p[k+1] ← p[k] ^ p[0]_(size+k) ? (0^(size-k) || 1^1 || b || 0^k) : 0^(2*size)
	endfor
	c ← p[size]_(size-1..0)
enddef

def EnsembleTernary(op,size,rd,rc,rb,ra) as
	d ← RegRead(rd, 128)
	c ← RegRead(rc, 128)
	b ← RegRead(rb, 128)
	case op of
		E.MUL.G:
			for i ← 0 to 128-size by size
				a_(size-1+i..i) ← PolyResidue(size,PolyMul(size,c_(size-1+i..i),b_(size-1+i..i)),d_(size-1+i..i))
			endfor
	endcase
	RegWrite(ra, 128, a)
enddef
```

Exceptions

none

Fig. 42C



Ensemble multiply Galois field bytes

Fig. 42D

X.COMPRESS.2	Crossbar compress signed pecks
X.COMPRESS.4	Crossbar compress signed nibbles
X.COMPRESS.8	Crossbar compress signed bytes
X.COMPRESS.16	Crossbar compress signed doublets
X.COMPRESS.32	Crossbar compress signed quadlets
X.COMPRESS.64	Crossbar compress signed octlets
X.COMPRESS.128	Crossbar compress signed hexlet
X.COMPRESS.U.2	Crossbar compress unsigned pecks
X.COMPRESS.U.4	Crossbar compress unsigned nibbles
X.COMPRESS.U.8	Crossbar compress unsigned bytes
X.COMPRESS.U.16	Crossbar compress unsigned doublets
X.COMPRESS.U.32	Crossbar compress unsigned quadlets
X.COMPRESS.U.64	Crossbar compress unsigned octlets
X.COMPRESS.U.128	Crossbar compress unsigned hexlet
X.EXPAND.2	Crossbar expand signed pecks
X.EXPAND.4	Crossbar expand signed nibbles
X.EXPAND.8	Crossbar expand signed bytes
X.EXPAND.16	Crossbar expand signed doublets
X.EXPAND.32	Crossbar expand signed quadlets
X.EXPAND.64	Crossbar expand signed octlets
X.EXPAND.128	Crossbar expand signed hexlet
X.EXPAND.U.2	Crossbar expand unsigned pecks
X.EXPAND.U.4	Crossbar expand unsigned nibbles
X.EXPAND.U.8	Crossbar expand unsigned bytes
X.EXPAND.U.16	Crossbar expand unsigned doublets
X.EXPAND.U.32	Crossbar expand unsigned quadlets
X.EXPAND.U.64	Crossbar expand unsigned octlets
X.EXPAND.U.128	Crossbar expand unsigned hexlet
X.ROTL.2	Crossbar rotate left pecks
X.ROTL.4	Crossbar rotate left nibbles
X.ROTL.8	Crossbar rotate left bytes
X.ROTL.16	Crossbar rotate left doublets
X.ROTL.32	Crossbar rotate left quadlets
X.ROTL.64	Crossbar rotate left octlets
X.ROTL.128	Crossbar rotate left hexlet
X.ROTR.2	Crossbar rotate right pecks
X.ROTR.4	Crossbar rotate right nibbles
X.ROTR.8	Crossbar rotate right bytes
X.ROTR.16	Crossbar rotate right doublets

Fig. 43A

X.ROTR.32	Crossbar rotate right quadlets
X.ROTR.64	Crossbar rotate right octlets
X.ROTR.128	Crossbar rotate right hexlet
X.SHL.2	Crossbar shift left pecks
X.SHL.2.O	Crossbar shift left signed pecks check overflow
X.SHL.4	Crossbar shift left nibbles
X.SHL.4.O	Crossbar shift left signed nibbles check overflow
X.SHL.8	Crossbar shift left bytes
X.SHL.8.O	Crossbar shift left signed bytes check overflow
X.SHL.16	Crossbar shift left doublets
X.SHL.16.O	Crossbar shift left signed doublets check overflow
X.SHL.32	Crossbar shift left quadlets
X.SHL.32.O	Crossbar shift left signed quadlets check overflow
X.SHL.64	Crossbar shift left octlets
X.SHL.64.O	Crossbar shift left signed octlets check overflow
X.SHL.128	Crossbar shift left hexlet
X.SHL.128.O	Crossbar shift left signed hexlet check overflow
X.SHL.U.2.O	Crossbar shift left unsigned pecks check overflow
X.SHL.U.4.O	Crossbar shift left unsigned nibbles check overflow
X.SHL.U.8.O	Crossbar shift left unsigned bytes check overflow
X.SHL.U.16.O	Crossbar shift left unsigned doublets check overflow
X.SHL.U.32.O	Crossbar shift left unsigned quadlets check overflow
X.SHL.U.64.O	Crossbar shift left unsigned octlets check overflow
X.SHL.U.128.O	Crossbar shift left unsigned hexlet check overflow
X.SHR.2	Crossbar signed shift right pecks
X.SHR.4	Crossbar signed shift right nibbles
X.SHR.8	Crossbar signed shift right bytes
X.SHR.16	Crossbar signed shift right doublets
X.SHR.32	Crossbar signed shift right quadlets
X.SHR.64	Crossbar signed shift right octlets
X.SHR.128	Crossbar signed shift right hexlet
X.SHR.U.2	Crossbar shift right unsigned pecks
X.SHR.U.4	Crossbar shift right unsigned nibbles
X.SHR.U.8	Crossbar shift right unsigned bytes
X.SHR.U.16	Crossbar shift right unsigned doublets
X.SHR.U.32	Crossbar shift right unsigned quadlets
X.SHR.U.64	Crossbar shift right unsigned octlets
X.SHR.U.128	Crossbar shift right unsigned hexlet

Fig. 43A (cont'd)

Selection

class	op	size
precision	EXPAND EXPAND.U COMPRESS COMPRESS.U	2 4 8 16 32 64 128
shift	ROTR ROTL SHR SHL SHL.O SHL.U.O SHR.U	2 4 8 16 32 64 128

Format

X.op.size rd=rc,rb

rd=xopsize(rc,rb)

31 25	24	23 18	17 12	11 6	5 2	1 0
XSHIFT	**s**	**rd**	**rc**	**rb**	**op**	**sz**
7	1	6	6	6	4	2

lsize ← log(size)
s ← $lsize_2$
sz ← $lsize_{1..0}$

Fig. 43B

Definition

def Crossbar(op,size,rd,rc,rb)
c ← RegRead(rc, 128)
b ← RegRead(rb, 128)
shift ← b and (size-1)
case $op_{5..2} \| 0^2$ of
X.COMPRESS:
hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+hsize-1..i} \leftarrow c_{i+i+shift+hsize-1..i+i+shift}$
else
$a_{i+hsize-1..i} \leftarrow c_{i+i+size-1}^{shift-hsize} \| c_{i+i+size-1..i+i+shift}$
endif
endfor
$a_{127..64} \leftarrow 0$
X.COMPRESS.U:
hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+hsize-1..i} \leftarrow c_{i+i+shift+hsize-1..i+i+shift}$
else
$a_{i+hsize-1..i} \leftarrow 0^{shift-hsize} \| c_{i+i+size-1..i+i+shift}$
endif
endfor
$a_{127..64} \leftarrow 0$
X.EXPAND:
hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+i+size-1..i+i} \leftarrow c_{i+hsize-1}^{hsize-shift} \| c_{i+hsize-1..i} \| 0^{shift}$
else
$a_{i+i+size-1..i+i} \leftarrow c_{i+size-shift-1..i} \| 0^{shift}$
endif
endfor
X.EXPAND.U:
hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+i+size-1..i+i} \leftarrow 0^{hsize-shift} \| c_{i+hsize-1..i} \| 0^{shift}$
else
$a_{i+i+size-1..i+i} \leftarrow c_{i+size-shift-1..i} \| 0^{shift}$
endif
endfor
X.ROTL:
for i ← 0 to 128-size by size
$a_{i+size-1..i} \leftarrow c_{i+size-1-shift..i} \| c_{i+size-1..i+size-1-shift}$
endfor

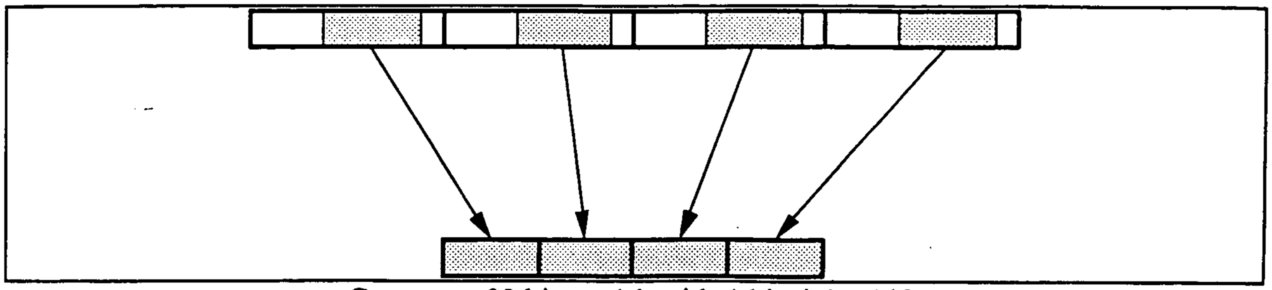
Fig. 43C

```
        X.ROTR:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← c[i+shift-1..i] || c[i+size-1..i+shift]
            endfor
        X.SHL:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← c[i+size-1-shift..i] || 0^shift
            endfor
        X.SHL.O:
            for i ← 0 to 128-size by size
                if c[i+size-1..i+size-1-shift] ≠ c[i+size-1-shift]^(shift+1) then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← c[i+size-1-shift..i] || 0^shift
            endfor
        X.SHL.U.O:
            for i ← 0 to 128-size by size
                if c[i+size-1..i+size-shift] ≠ 0^shift then
                    raise FixedPointArithmetic
                endif
                a[i+size-1..i] ← c[i+size-1-shift..i] || 0^shift
            endfor
        X.SHR:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← c[i+size-1]^shift || c[i+size-1..i+shift]
            endfor
        X.SHR.U:
            for i ← 0 to 128-size by size
                a[i+size-1..i] ← 0^shift || c[i+size-1..i+shift]
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Fixed-point arithmetic

Fig. 43C (cont'd)



Compress 32 bits to 16, with 4-bit right shift

Fig. 43D

Operation codes

X.SHL.M.2	Crossbar shift left merge pecks
X.SHL.M.4	Crossbar shift left merge nibbles
X.SHL.M.8	Crossbar shift left merge bytes
X.SHL.M.16	Crossbar shift left merge doublets
X.SHL.M.32	Crossbar shift left merge quadlets
X.SHL.M.64	Crossbar shift left merge octlets
X.SHL.M.128	Crossbar shift left merge hexlet
X.SHR.M.2	Crossbar shift right merge pecks
X.SHR.M.4	Crossbar shift right merge nibbles
X.SHR.M.8	Crossbar shift right merge bytes
X.SHR.M.16	Crossbar shift right merge doublets
X.SHR.M.32	Crossbar shift right merge quadlets
X.SHR.M.64	Crossbar shift right merge octlets
X.SHR.M.128	Crossbar shift right merge hexlet

Fig. 43E

Format

X.op.size rd@rc,rb

rd=xopsize(rd,rc,rb)

31 25	24	23 18	17 12	11 6	5 2	1 0
XSHIFT	s	rd	rc	rb	op	sz
7	1	6	6	6	4	2

$\text{lsize} \leftarrow \log(\text{size})$
$s \leftarrow \text{lsize}_2$
$sz \leftarrow \text{lsize}_{1..0}$

Fig 43F

Definition

```
def CrossbarInplace(op,size,rd,rc,rb) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    shift ← b and (size-1)
    for i ← 0 to 128-size by size
        case op of
            X.SHR.M:
                a[i+size-1..i] ← c[i+shift-1..i] || d[i+size-1..i+shift]
            X.SHL.M:
                a[i+size-1..i] ← d[i+size-1-shift..i] || c[i+shift-1..i]
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig 43G

Operation codes

X.COMPRESS.I.2	Crossbar compress immediate signed pecks
X.COMPRESS.I.4	Crossbar compress immediate signed nibbles
X.COMPRESS.I.8	Crossbar compress immediate signed bytes
X.COMPRESS.I.16	Crossbar compress immediate signed doublets
X.COMPRESS.I.32	Crossbar compress immediate signed quadlets
X.COMPRESS.I.64	Crossbar compress immediate signed octlets
X.COMPRESS.I.128	Crossbar compress immediate signed hexlet
X.COMPRESS.I.U.2	Crossbar compress immediate unsigned pecks
X.COMPRESS.I.U.4	Crossbar compress immediate unsigned nibbles
X.COMPRESS.I.U.8	Crossbar compress immediate unsigned bytes
X.COMPRESS.I.U.16	Crossbar compress immediate unsigned doublets
X.COMPRESS.I.U.32	Crossbar compress immediate unsigned quadlets
X.COMPRESS.I.U.64	Crossbar compress immediate unsigned octlets
X.COMPRESS.I.U.128	Crossbar compress immediate unsigned hexlet
X.EXPAND.I.2	Crossbar expand immediate signed pecks
X.EXPAND.I.4	Crossbar expand immediate signed nibbles
X.EXPAND.I.8	Crossbar expand immediate signed bytes
X.EXPAND.I.16	Crossbar expand immediate signed doublets
X.EXPAND.I.32	Crossbar expand immediate signed quadlets
X.EXPAND.I.64	Crossbar expand immediate signed octlets
X.EXPAND.I.128	Crossbar expand immediate signed hexlet
X.EXPAND.I.U.2	Crossbar expand immediate unsigned pecks
X.EXPAND.I.U.4	Crossbar expand immediate unsigned nibbles
X.EXPAND.I.U.8	Crossbar expand immediate unsigned bytes
X.EXPAND.I.U.16	Crossbar expand immediate unsigned doublets
X.EXPAND.I.U.32	Crossbar expand immediate unsigned quadlets
X.EXPAND.I.U.64	Crossbar expand immediate unsigned octlets
X.EXPAND.I.U.128	Crossbar expand immediate unsigned hexlet
X.ROTL.I.2	Crossbar rotate left immediate pecks
X.ROTL.I.4	Crossbar rotate left immediate nibbles
X.ROTL.I.8	Crossbar rotate left immediate bytes
X.ROTL.I.16	Crossbar rotate left immediate doublets
X.ROTL.I.32	Crossbar rotate left immediate quadlets
X.ROTL.I.64	Crossbar rotate left immediate octlets
X.ROTL.I.128	Crossbar rotate left immediate hexlet
X.ROTR.I.2	Crossbar rotate right immediate pecks
X.ROTR.I.4	Crossbar rotate right immediate nibbles
X.ROTR.I.8	Crossbar rotate right immediate bytes
X.ROTR.I.16	Crossbar rotate right immediate doublets
X.ROTR.I.32	Crossbar rotate right immediate quadlets
X.ROTR.I.64	Crossbar rotate right immediate octlets
X.ROTR.I.128	Crossbar rotate right immediate hexlet

Fig. 43H

X.SHL.I.2	Crossbar shift left immediate pecks
X.SHL.I.2.O	Crossbar shift left immediate signed pecks check overflow
X.SHL.I.4	Crossbar shift left immediate nibbles
X.SHL.I.4.O	Crossbar shift left immediate signed nibbles check overflow
X.SHL.I.8	Crossbar shift left immediate bytes
X.SHL.I.8.O	Crossbar shift left immediate signed bytes check overflow
X.SHL.I.16	Crossbar shift left immediate doublets
X.SHL.I.16.O	Crossbar shift left immediate signed doublets check overflow
X.SHL.I.32	Crossbar shift left immediate quadlets
X.SHL.I.32.O	Crossbar shift left immediate signed quadlets check overflow
X.SHL.I.64	Crossbar shift left immediate octlets
X.SHL.I.64.O	Crossbar shift left immediate signed octlets check overflow
X.SHL.I.128	Crossbar shift left immediate hexlet
X.SHL.I.128.O	Crossbar shift left immediate signed hexlet check overflow
X.SHL.I.U.2.O	Crossbar shift left immediate unsigned pecks check overflow
X.SHL.I.U.4.O	Crossbar shift left immediate unsigned nibbles check overflow
X.SHL.I.U.8.O	Crossbar shift left immediate unsigned bytes check overflow
X.SHL.I.U.16.O	Crossbar shift left immediate unsigned doublets check overflow
X.SHL.I.U.32.O	Crossbar shift left immediate unsigned quadlets check overflow
X.SHL.I.U.64.O	Crossbar shift left immediate unsigned octlets check overflow
X.SHL.I.U.128.O	Crossbar shift left immediate unsigned hexlet check overflow
X.SHR.I.2	Crossbar signed shift right immediate pecks
X.SHR.I.4	Crossbar signed shift right immediate nibbles
X.SHR.I.8	Crossbar signed shift right immediate bytes
X.SHR.I.16	Crossbar signed shift right immediate doublets
X.SHR.I.32	Crossbar signed shift right immediate quadlets
X.SHR.I.64	Crossbar signed shift right immediate octlets
X.SHR.I.128	Crossbar signed shift right immediate hexlet
X.SHR.I.U.2	Crossbar shift right immediate unsigned pecks
X.SHR.I.U.4	Crossbar shift right immediate unsigned nibbles
X.SHR.I.U.8	Crossbar shift right immediate unsigned bytes
X.SHR.I.U.16	Crossbar shift right immediate unsigned doublets
X.SHR.I.U.32	Crossbar shift right immediate unsigned quadlets
X.SHR.I.U.64	Crossbar shift right immediate unsigned octlets
X.SHR.I.U.128	Crossbar shift right immediate unsigned hexlet

Fig. 43H (cont)

Selection

class	op	size
precision	COMPRESS.I COMPRESS.I.U EXPAND.I EXPAND.I.U	2 4 8 16 32 64 128
shift	ROTL.I ROTR.I SHL.I SHL.I.O SHL.I.U.O SHR.I SHR.I.U	2 4 8 16 32 64 128
copy	*COPY*	

Format

X.op.size rd=rc,shift

rd=xopsize(rc,shift)

31 24	23 18	17 12	11 6	5 0
XSHIFTI	**rd**	**rc**	**simm**	**op**
8	6	6	6	6

$t \leftarrow 256-2*size+shift$
$op_{1..0} \leftarrow t_{7..6}$
$simm \leftarrow t_{5..0}$

Fig. 43I

Definition

```
def CrossbarShortImmediate(op,rd,rc,simm)
    case (op_{1..0} || simm) of
        0..127:
            size ← 128
        128..191:
            size ← 64
        192..223:
            size ← 32
        224..239:
            size ← 16
        240..247:
            size ← 8
        248..251:
            size ← 4
        252..253:
            size ← 2
        254..255:
            raise ReservedInstruction
    endcase
    shift ← (op_0 || simm) and (size-1)
    c ← RegRead(rc, 128)
    case (op_{5..2} || 0^2) of
        X.COMPRESS.I:
            hsize ← size/2
            for i ← 0 to 64-hsize by hsize
                if shift ≤ hsize then
                    a_{i+hsize-1..i} ← c_{i+i+shift+hsize-1..i+i+shift}
                else
                    a_{i+hsize-1..i} ← c_{i+i+size-1}^{shift-hsize} || c_{i+i+size-1..i+i+shift}
                endif
            endfor
            a_{127..64} ← 0
        X.COMPRESS.I.U:
            hsize ← size/2
            for i ← 0 to 64-hsize by hsize
                if shift ≤ hsize then
                    a_{i+hsize-1..i} ← c_{i+i+shift+hsize-1..i+i+shift}
                else
                    a_{i+hsize-1..i} ← 0^{shift-hsize} || c_{i+i+size-1..i+i+shift}
                endif
            endfor
            a_{127..64} ← 0
```

Fig. 43J

X.EXPAND.I:

hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+i+size-1..i+i} \leftarrow c_{i+hsize-1}^{hsize-shift} \| c_{i+hsize-1..i} \| 0^{shift}$
else
$a_{i+i+size-1..i+i} \leftarrow c_{i+size-shift-1..i} \| 0^{shift}$
endif
endfor

X.EXPAND.I.U:

hsize ← size/2
for i ← 0 to 64-hsize by hsize
if shift ≤ hsize then
$a_{i+i+size-1..i+i} \leftarrow 0^{hsize-shift} \| c_{i+hsize-1..i} \| 0^{shift}$
else
$a_{i+i+size-1..i+i} \leftarrow c_{i+size-shift-1..i} \| 0^{shift}$
endif
endfor

X.SHL.I:

for i ← 0 to 128-size by size
$a_{i+size-1..i} \leftarrow c_{i+size-1-shift..i} \| 0^{shift}$
endfor

X.SHL.I.O:

for i ← 0 to 128-size by size
if $c_{i+size-1..i+size-1-shift} \neq c_{i+size-1-shift}^{shift+1}$ then
raise FixedPointArithmetic
endif
$a_{i+size-1..i} \leftarrow c_{i+size-1-shift..i} \| 0^{shift}$
endfor

X.SHL.I.U.O:

for i ← 0 to 128-size by size
if $c_{i+size-1..i+size-shift} \neq 0^{shift}$ then
raise FixedPointArithmetic
endif
$a_{i+size-1..i} \leftarrow c_{i+size-1-shift..i} \| 0^{shift}$
endfor

Fig. 43J (cont)

```
        X.ROTR.I:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← c_{i+shift-1..i} || c_{i+size-1..i+shift}
            endfor
        X.SHR.I:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← c_{i+size-1}^{shift} || c_{i+size-1..i+shift}
            endfor
        X.SHR.I.U:
            for i ← 0 to 128-size by size
                a_{i+size-1..i} ← 0^{shift} || c_{i+size-1..i+shift}
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Fixed-point arithmetic
Reserved Instruction

Fig. 43J (cont)

Operation codes

X.SHL.M.I.2	Crossbar shift left merge immediate pecks
X.SHL.M.I.4	Crossbar shift left merge immediate nibbles
X.SHL.M.I.8	Crossbar shift left merge immediate bytes
X.SHL.M.I.16	Crossbar shift left merge immediate doublets
X.SHL.M.I.32	Crossbar shift left merge immediate quadlets
X.SHL.M.I.64	Crossbar shift left merge immediate octlets
X.SHL.M.I.128	Crossbar shift left merge immediate hexlet
X.SHR.M.I.2	Crossbar shift right merge immediate pecks
X.SHR.M.I.4	Crossbar shift right merge immediate nibbles
X.SHR.M.I.8	Crossbar shift right merge immediate bytes
X.SHR.M.I.16	Crossbar shift right merge immediate doublets
X.SHR.M.I.32	Crossbar shift right merge immediate quadlets
X.SHR.M.I.64	Crossbar shift right merge immediate octlets
X.SHR.M.I.128	Crossbar shift right merge immediate hexlet

Fig 43K

Format

X.op.size rd@rc,shift

rd=xopsize(rc,shift)

31 24	23 18	17 12	11 6	5 0
XSHIFTI	rd	rc	simm	op
8	6	6	6	6

$t \leftarrow 256\text{-}2^*size+shift$
$op_{1..0} \leftarrow t_{7..6}$
$simm \leftarrow t_{5..0}$

Fig 43L

Definition

```
def CrossbarShortImmediateInplace(op,rd,rc,simm)
    case (op1..0 || simm) of
        0..127:
            size ← 128
        128..191:
            size ← 64
        192..223:
            size ← 32
        224..239:
            size ← 16
        240..247:
            size ← 8
        248..251:
            size ← 4
        252..253:
            size ← 2
        254..255:
            raise ReservedInstruction
    endcase
    shift ← (op0 || simm) and (size-1)
    c ← RegRead(rc, 128)
    d ← RegRead(rd, 128)
    for i ← 0 to 128-size by size
        case (op5..2 || 0^2) of
            X.SHR.M.I:
                a[i+size-1..i] ← c[i+shift-1..i] || d[i+size-1..i+shift]
            X.SHL.M.I:
                a[i+size-1..i] ← d[i+size-1-shift..i] || c[i+shift-1..i]
        endcase
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Reserved Instruction

Fig 43M

Format

X.EXTRACT ra=rd,rc,rb

ra=xextract(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 44A

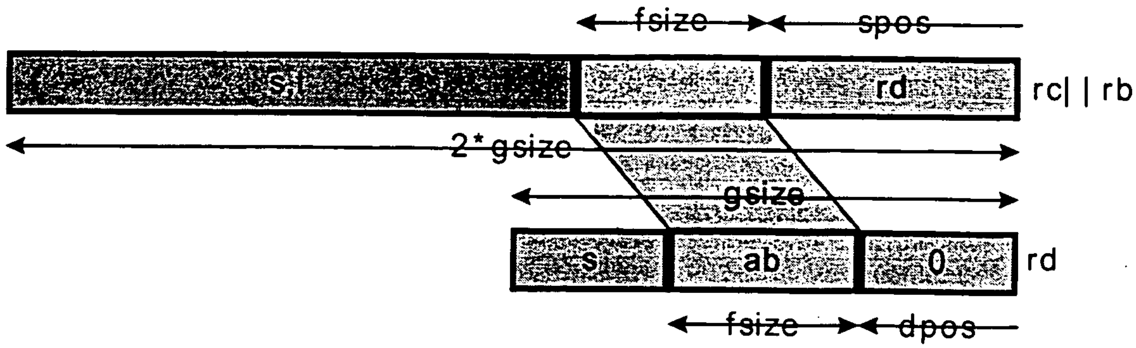
Definition

```
def CrossbarExtract(op,ra,rb,rc,rd) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case b8..0 of
        0..255:
            gsize ← 128
        256..383:
            gsize ← 64
        384..447:
            gsize ← 32
        448..479:
            gsize ← 16
        480..495:
            gsize ← 8
        496..503:
            gsize ← 4
        504..507:
            gsize ← 2
        508..511:
            gsize ← 1
    endcase
    m ← b12
    as ← signed ← b14
    h ← (2-m)*gsize
    spos ← (b8..0) and ((2-m)*gsize-1)
    dpos ← (0 || b23..16) and (gsize-1)
    sfsize ← (0 || b31..24) and (gsize-1)
    tfsize ← (sfsize = 0) or ((sfsize+dpos) > gsize) ? gsize-dpos : sfsize
    fsize ← (tfsize + spos > h) ? h - spos : tfsize
    for i ← 0 to 128-gsize by gsize
        case op of
            X.EXTRACT:
                if m then
                    p ← dgsize+i-1..i
                else
                    p ← (d || c)2*(gsize+i)-1..2*i
                endif
        endcase
        v ← (as & ph-1)||p
        w ← (as & vspos+fsize-1)^(gsize-fsize-dpos) || vfsize-1+spos..spos || 0^dpos
        if m then
            asize-1+i..i ← cgsize-1+i..dpos+fsize+i || wdpos+fsize-1..dpos || cdpos-1+1..i
        else
            asize-1+i..i ← w
        endif
    endfor
    RegWrite(ra, 128, a)
enddef
```

Exceptions

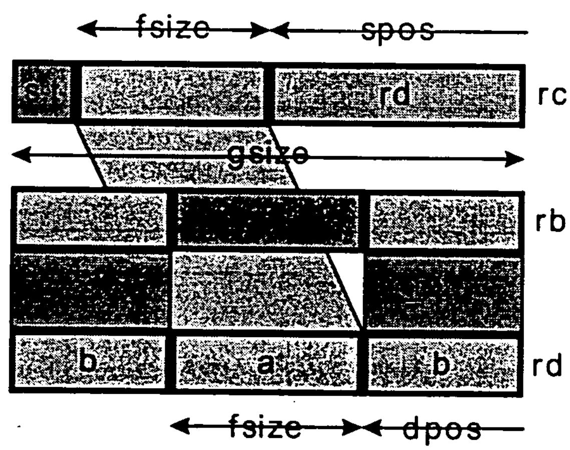
none

Fig. 44B



Crossbar extract

Fig. 44C



Crossbar merge extract

Fig. 44D

Operation codes

E.MUL.X	Ensemble multiply extract
E.EXTRACT	Ensemble extract
E.SCAL.ADD.X	Ensemble scale add extract

Fig. 44E

Format

E.op ra=rd,rc,rb

ra=eop(rd,rc,rb)

31 … 24	23 … 18	17 … 12	11 … 6	5 … 0
op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 44F

```
def mul(size,h,vs,v,i,ws,w,j) as
    mul ← ((vs&v_{size-1+i})^{h-size} || v_{size-1+i..i}) * ((ws&w_{size-1+j})^{h-size} || w_{size-1+j..j})
enddef

def EnsembleExtract(op,ra,rb,rc,rd) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    case b_{8..0} of
        0..255:
            sgsize ← 128
        256..383:
            sgsize ← 64
        384..447:
            sgsize ← 32
        448..479:
            sgsize ← 16
        480..495:
            sgsize ← 8
        496..503:
            sgsize ← 4
        504..507:
            sgsize ← 2
        508..511:
            sgsize ← 1
    endcase
    l ← b_{11}
    m ← b_{12}
    n ← b_{13}
    signed ← b_{14}
    case op of
        E.EXTRACT:
            gsize ← sgsize
            h ← (2-m)*gsize
            as ← signed
            spos ← (b_{8..0}) and ((2-m)*gsize-1)
        E.SCAL.ADD.X:
            if (sgsize < 8) then
                gsize ← 8
            elseif (sgsize*(n+1) > 32) then
                gsize ← 32/(n+1)
            else
                gsize ← sgsize
            endif
            ds ← cs ← signed
            bs ← signed ^ m
            as ← signed or m or n
            h ← (2*gsize) + 1 + n
            spos ← (b_{8..0}) and (2*gsize-1)
```

Fig. 44G

```
        E.MUL.X:
                if (sgsize < 8) then
                        gsize ← 8
                elseif (sgsize*(n+1) > 128) then
                        gsize ← 128/(n+1)
                else
                        gsize ← sgsize
                endif
                ds ← signed
                cs ← signed ^ m
                as ← signed or m or n
                h ← (2*gsize) + n
                spos ← (b8..0) and (2*gsize-1)
endcase
dpos ← (0 || b23..16) and (gsize-1)
r ← spos
sfsize ← (0 || b31..24) and (gsize-1)
tfsize ← (sfsize = 0) or ((sfsize+dpos) > gsize) ? gsize-dpos : sfsize
fsize ← (tfsize + spos > h) ? h - spos : tfsize
if (b10..9 = Z) and not as then
        rnd ← F
else
        rnd ← b10..9
endif
for i ← 0 to 128-gsize by gsize
        case op of
                E.EXTRACT:
                        if m then
                                p ← dgsize+i-1..i
                        else
                                p ← (d || c)2*(gsize+i)-1..2*i
                        endif
                E.MUL.X:
                        if n then
                                if (i and gsize) = 0 then
                                        p ← mul(gsize,h,ds,d,i,cs,c,i) - mul(gsize,h,ds,d,i+size,cs,c,i+size)
                                else
                                        p ← mul(gsize,h,ds,d,i,cs,c,i+size) + mul(gsize,h,ds,d,i,cs,c,i+size)
                                endif
                        else
                                p ← mul(gsize,h,ds,d,i,cs,c,i)
                        endif
```

Fig. 44G (cont)

E.SCAL.ADD.X:
if n then
if (i and gsize) = 0 then
$p \leftarrow$ mul(gsize,h,ds,d,i,bs,b,64+2*gsize)
\+ mul(gsize,h,cs,c,i,bs,b,64)
\- mul(gsize,h,ds,d,i+gsize,bs,b,64+3*gsize)
\- mul(gsize,h,cs,c,i+gsize,bs,b,64+gsize)
else
$p \leftarrow$ mul(gsize,h,ds,d,i,bs,b,64+3*gsize)
\+ mul(gsize,h,cs,c,i,bs,b,64+gsize)
\+ mul(gsize,h,ds,d,i+gsize,bs,b,64+2*gsize)
\+ mul(gsize,h,cs,c,i+gsize,bs,b,64)
endif
else
$p \leftarrow$ mul(gsize,h,ds,d,i,bs,b,64+gsize) + mul(gsize,h,cs,c,i,bs,b,64)
endif
endcase
case rnd of
N:
$s \leftarrow 0^{h-r} \,||\, \sim p_r \,||\, p_r^{r-1}$
Z:
$s \leftarrow 0^{h-r} \,||\, p_{h-1}^{r}$
F:
$s \leftarrow 0^{h}$
C:
$s \leftarrow 0^{h-r} \,||\, 1^{r}$
endcase
$v \leftarrow ((as \,\&\, p_{h-1})||p) + (0||s)$
if $(v_{h..r+fsize} = (as \,\&\, v_{r+fsize-1})^{h+1-r-fsize})$ or not (l and (op = E.EXTRACT)) then
$w \leftarrow (as \,\&\, v_{r+fsize-1})^{gsize-fsize-dpos} \,||\, v_{fsize-1+r..r} \,||\, 0^{dpos}$
else
$w \leftarrow (s \,?\, (v_h \,||\, \sim v_h^{gsize-dpos-1}) : 1^{gsize-dpos}) \,||\, 0^{dpos}$
endif
if m and (op = E.EXTRACT) then
$a_{size-1+i..i} \leftarrow c_{gsize-1+i..dpos+fsize+i} \,||\, w_{dpos+fsize-1..dpos} \,||\, c_{dpos-1+1..i}$
else
$a_{size-1+i..i} \leftarrow w$
endif
endfor
RegWrite(ra, 128, a)
enddef

Exceptions

none

Fig. 44G (cont)

X.DEPOSIT.2	Crossbar deposit signed pecks
X.DEPOSIT.4	Crossbar deposit signed nibbles
X.DEPOSIT.8	Crossbar deposit signed bytes
X.DEPOSIT.16	Crossbar deposit signed doublets
X.DEPOSIT.32	Crossbar deposit signed quadlets
X.DEPOSIT.64	Crossbar deposit signed octlets
X.DEPOSIT.128	Crossbar deposit signed hexlet
X.DEPOSIT.U.2	Crossbar deposit unsigned pecks
X.DEPOSIT.U.4	Crossbar deposit unsigned nibbles
X.DEPOSIT.U.8	Crossbar deposit unsigned bytes
X.DEPOSIT.U.16	Crossbar deposit unsigned doublets
X.DEPOSIT.U.32	Crossbar deposit unsigned quadlets
X.DEPOSIT.U.64	Crossbar deposit unsigned octlets
X.DEPOSIT.U.128	Crossbar deposit unsigned hexlet
X.WITHDRAW.U.2	Crossbar withdraw unsigned pecks
X.WITHDRAW.U.4	Crossbar withdraw unsigned nibbles
X.WITHDRAW.U.8	Crossbar withdraw unsigned bytes
X.WITHDRAW.U.16	Crossbar withdraw unsigned doublets
X.WITHDRAW.U.32	Crossbar withdraw unsigned quadlets
X.WITHDRAW.U.64	Crossbar withdraw unsigned octlets
X.WITHDRAW.U.128	Crossbar withdraw unsigned hexlet
X.WITHDRAW.2	Crossbar withdraw pecks
X.WITHDRAW.4	Crossbar withdraw nibbles
X.WITHDRAW.8	Crossbar withdraw bytes
X.WITHDRAW.16	Crossbar withdraw doublets
X.WITHDRAW.32	Crossbar withdraw quadlets
X.WITHDRAW.64	Crossbar withdraw octlets
X.WITHDRAW.128	Crossbar withdraw hexlet

Fig. 45A

Equivalencies

X.SEX.I.2	Crossbar extend immediate signed pecks
X.SEX.I.4	Crossbar extend immediate signed nibbles
X.SEX.I.8	Crossbar extend immediate signed bytes
X.SEX.I.16	Crossbar extend immediate signed doublets
X.SEX.I.32	Crossbar extend immediate signed quadlets
X.SEX.I.64	Crossbar extend immediate signed octlets
X.SEX.I.128	Crossbar extend immediate signed hexlet
X.ZEX.I.2	Crossbar extend immediate unsigned pecks
X.ZEX.I.4	Crossbar extend immediate unsigned nibbles
X.ZEX.I.8	Crossbar extend immediate unsigned bytes
X.ZEX.I.16	Crossbar extend immediate unsigned doublets
X.ZEX.I.32	Crossbar extend immediate unsigned quadlets
X.ZEX.I.64	Crossbar extend immediate unsigned octlets
X.ZEX.I.128	Crossbar extend immediate unsigned hexlet

X.SHL.I.gsize rd=rc,i	→	X.DEPOSIT.gsize rd=rc,size-i,i
X.SHR.I.gsize rd=rc,i	→	X.WITHDRAW.gsize rd=rc,size-i,i
X.SHRU.I.gsize rd=rc,i	→	X.WITHDRAW.U.gsize rd=rc,size-i,i
X.SEX.I.gsize rd=rc,i	→	X.DEPOSIT.gsize rd=rc,i,0
X.ZEX.I.gsize rd=rc,i	→	X.DEPOSIT.U.gsize rd=rc,i,0

Redundancies

X.DEPOSIT.gsize rd=rc,gsize,0	⇔	X.COPY rd=rc
X.DEPOSIT.U.gsize rd=rc,gsize,0	⇔	X.COPY rd=rc
X.WITHDRAW.gsize rd=rc,gsize,0	⇔	X.COPY rd=rc
X.WITHDRAW.U.gsize rd=rc,gsize,0	⇔	X.COPY rd=rc

Fig. 45A (cont'd)

Format

X.op.gsize rd=rc,isize,ishift

rd=xopgsize(rc,isize,ishift)

31 26	25 24	23 18	17 12	11 6	5 0
op	**ih**	**rd**	**rc**	**gsfp**	**gsfs**
6	2	6	6	6	6

assert isize+ishift $\leq$ gsize
assert isize$\geq$1
ih_0 || gsfs $\leftarrow$ 128-gsize+isize-1
ih_1 || gsfp $\leftarrow$ 128-gsize+ishift

Fig. 45B

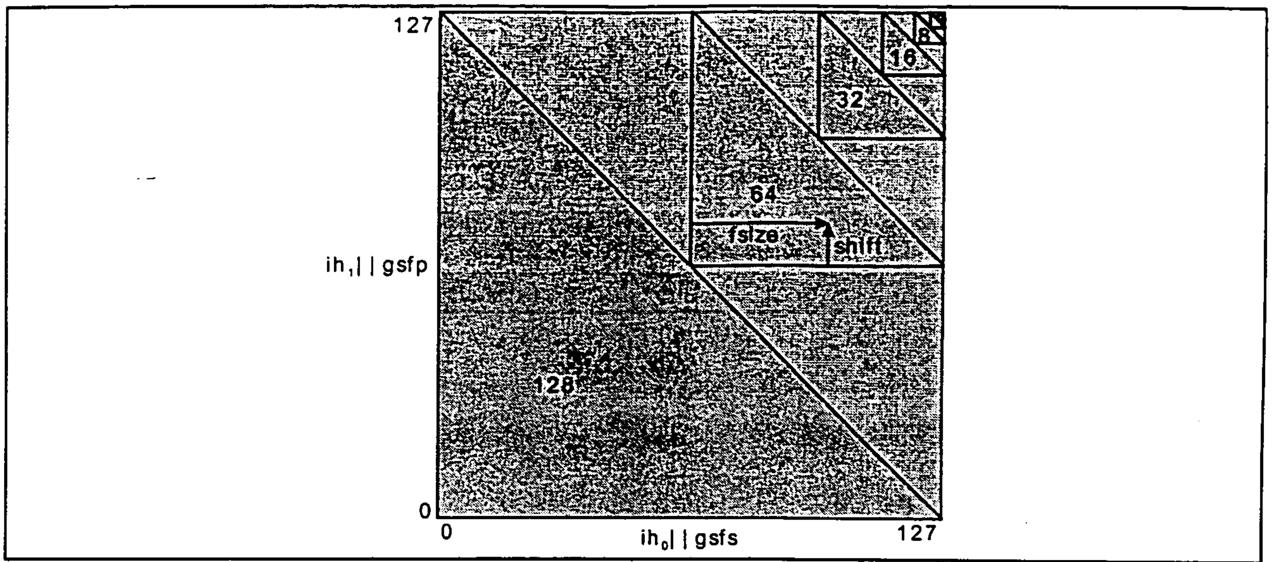
Definition

```
def CrossbarField(op,rd,rc,gsfp,gsfs) as
    c ← RegRead(rc, 128)
    case ((op_1 || gsfp) and (op_0 || gsfs)) of
        0..63:
            gsize ← 128
        64..95:
            gsize ← 64
        96..111:
            gsize ← 32
        112..119:
            gsize ← 16
        120..123:
            gsize ← 8
        124..125:
            gsize ← 4
        126:
            gsize ← 2
        127:
            raise ReservedInstruction
    endcase
    ishift ← (op_1 || gsfp) and (gsize-1)
    isize ← ((op_0 || gsfs) and (gsize-1))+1
    if (ishift+isize>gsize)
        raise ReservedInstruction
    endif
    case op of
        X.DEPOSIT:
            for i ← 0 to 128-gsize by gsize
                a_{i+gsize-1..i} ← c_{i+isize-1}^{gsize-isize-ishift} || c_{i+isize-1..i} || 0^{ishift}
            endfor
        X.DEPOSIT.U:
            for i ← 0 to 128-gsize by gsize
                a_{i+gsize-1..i} ← 0^{gsize-isize-ishift} || c_{i+isize-1..i} || 0^{ishift}
            endfor
        X.WITHDRAW:
            for i ← 0 to 128-gsize by gsize
                a_{i+gsize-1..i} ← c_{i+isize+ishift-1}^{size-isize} || c_{i+isize+ishift-1..i+ishift}
            endfor
        X.WITHDRAW.U:
            for i ← 0 to 128-gsize by gsize
                a_{i+gsize-1..i} ← 0^{gsize-isize} || c_{i+isize+ishift-1..i+ishift}
            endfor
    endcase
    RegWrite(rd, 128, a)
enddef
```

Exceptions

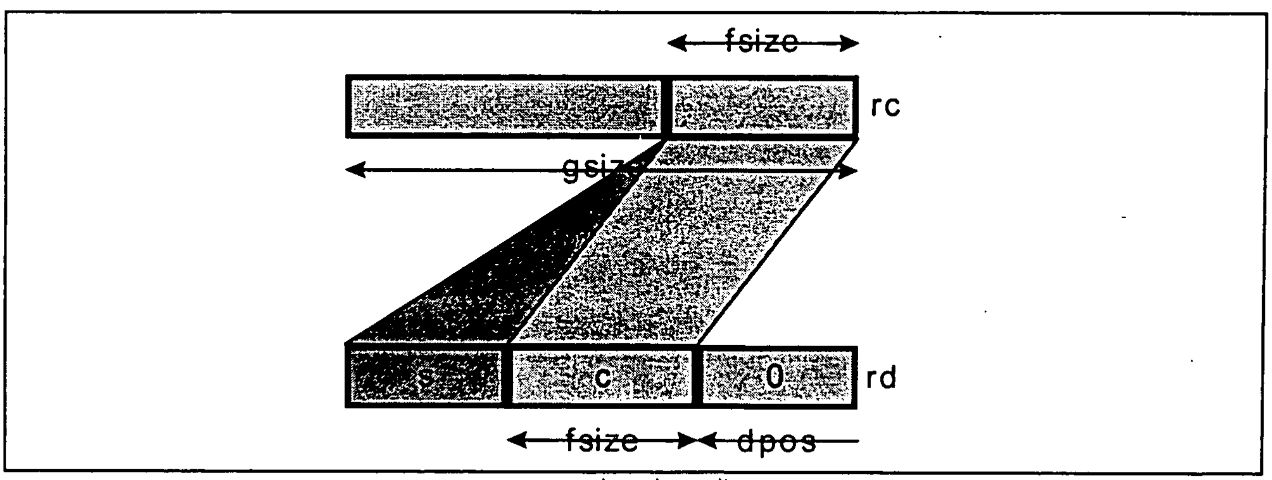
Reserved instruction

Fig. 45C



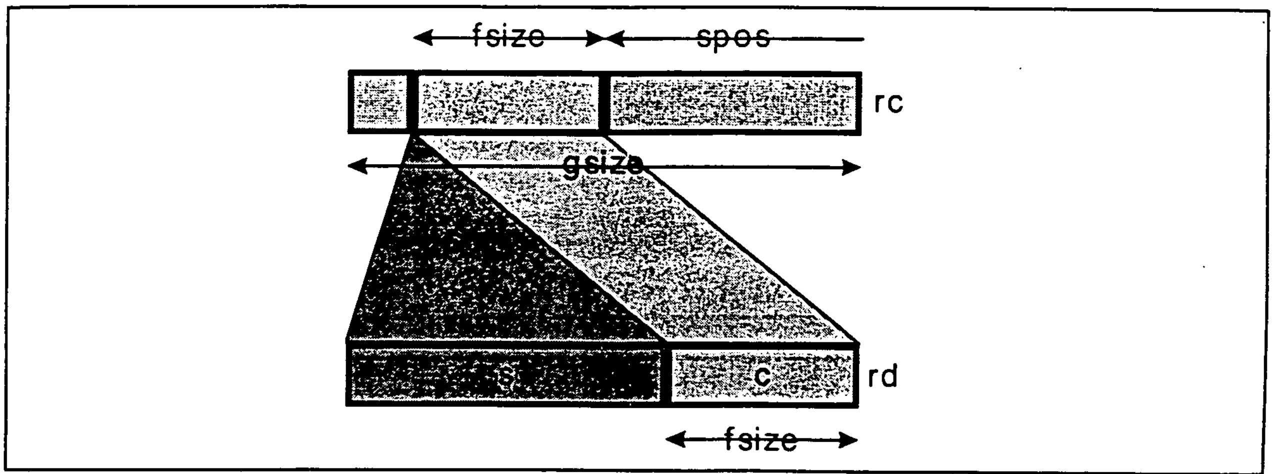
encoding for crossbar field

Fig. 45D



crossbar deposit

Fig. 45E



crossbar withdraw

Fig. 45F

Operation codes

X.DEPOSIT.M.2	Crossbar deposit merge pecks
X.DEPOSIT.M.4	Crossbar deposit merge nibbles
X.DEPOSIT.M.8	Crossbar deposit merge bytes
X.DEPOSIT.M.16	Crossbar deposit merge doublets
X.DEPOSIT.M.32	Crossbar deposit merge quadlets
X.DEPOSIT.M.64	Crossbar deposit merge octlets
X.DEPOSIT.M.128	Crossbar deposit merge hexlet

Fig 45G

Format

X.op.gsize rd@rc,isize,ishift

rd=xopgsize(rd,rc,isize,ishift)

31 26	25 24	23 18	17 12	11 6	5 0
op	ih	rd	rc	gsfp	gsfs
6	2	6	6	6	6

assert isize+ishift $\leq$ gsize
assert isize$\geq$1
ih_0 || gsfs $\leftarrow$ 128-gsize+isize-1
ih_1 || gsfp $\leftarrow$ 128-gsize+ishift

Fig 45H

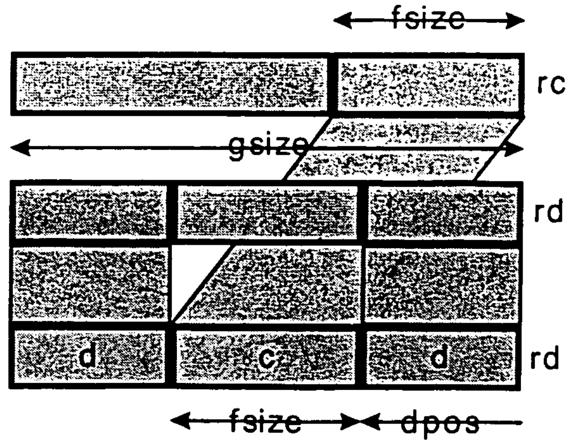
Definition

```
def CrossbarFieldInplace(op,rd,rc,gsfp,gsfs) as
    c ← RegRead(rc, 128)
    d ← RegRead(rd, 128)
    case ((op1 || gsfp) and (op0 || gsfs)) of
        0..63:
            gsize ← 128
        64..95:
            gsize ← 64
        96..111:
            gsize ← 32
        112..119:
            gsize ← 16
        120..123:
            gsize ← 8
        124..125:
            gsize ← 4
        126:
            gsize ← 2
        127:
            raise ReservedInstruction
    endcase
    ishift ← (op1 || gsfp) and (gsize-1)
    isize ← ((op0 || gsfs) and (gsize-1))+1
    if (ishift+isize>gsize)
        raise ReservedInstruction
    endif
    for i ← 0 to 128-gsize by gsize
        a[i+gsize-1..i] ← d[i+gsize-1..i+isize+ishift] || c[i+isize-1..i] || d[i+ishift-1..i]
    endfor
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Reserved instruction

Fig 45I



crossbar deposit merge

Fig 45J

X.SHUFFLE.4	Crossbar shuffle within pecks
X.SHUFFLE.8	Crossbar shuffle within bytes
X.SHUFFLE.16	Crossbar shuffle within doublets
X.SHUFFLE.32	Crossbar shuffle within quadlets
X.SHUFFLE.64	Crossbar shuffle within octlets
X.SHUFFLE.128	Crossbar shuffle within hexlet
X.SHUFFLE.256	Crossbar shuffle within triclet

Fig. 46A

Format

X.SHUFFLE.256 rd=rc,rb,v,w,h
X.SHUFFLE.size rd=rcb,v,w

rd=xshuffle256(rc,rb,v,w,h)
rd=xshufflesize(rcb,v,w)

31 24	23 18	17 12	11 6	5 0
X.SHUFFLE	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

rc ← rb ← rcb
x←$\log_2$(size)
y←$\log_2$(v)
z←$\log_2$(w)
op ← ((x*x*x-3*x*x-4*x)/6-(z*z-z)/2+x*z+y) + (size=256)*(h*32-56)

Fig. 46B

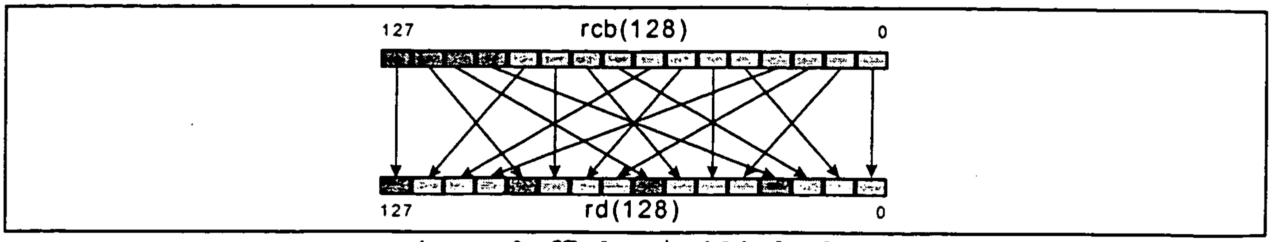
Definition

```
def CrossbarShuffle(major,rd,rc,rb,op)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    if rc=rb then
        case op of
            0..55:
                for x ← 2 to 7; for y ← 0 to x-2; for z ← 1 to x-y-1
                    if op = ((x*x*x-3*x*x-4*x)/6-(z*z-z)/2+x*z+y) then
                        for i ← 0 to 127
                            a_i ← c_(i_6..x || i_y+z-1..y || i_x-1..y+z || i_y-1..0)
                        end
                    endif
                endfor; endfor; endfor
            56..63:
                raise ReservedInstruction
        endcase
    elseif
        case op_4..0 of
            0..27:
                cb ← c || b
                x ← 8
                h ← op_5
                for y ← 0 to x-2; for z ← 1 to x-y-1
                    if op_4..0 = ((17*z-z*z)/2-8+y) then
                        for i ← h*128 to 127+h*128
                            a_i-h*128 ← cb_(i_y+z-1..y || i_x-1..y+z || i_y-1..0)
                        end
                    endif
                endfor; endfor
            28..31:
                raise ReservedInstruction
        endcase
    endif
    RegWrite(rd, 128, a)
enddef
```

Exceptions

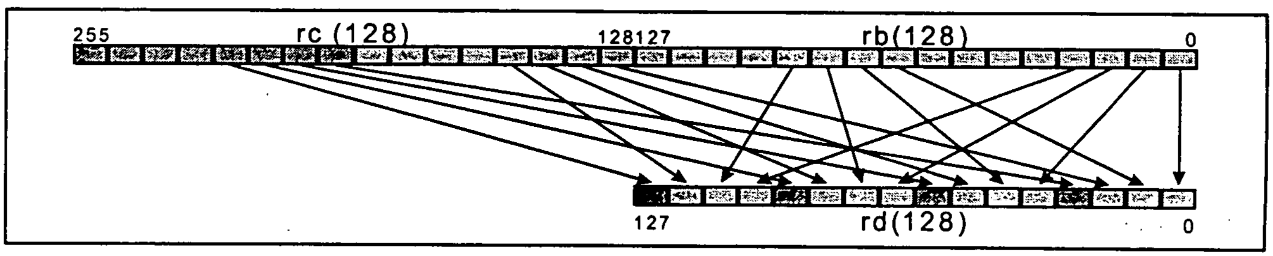
Reserved Instruction

Fig. 46C



4-way shuffle bytes within hexlet

Fig. 46D



4-way shuffle bytes within triclet

Fig. 46E

Format

X.SWIZZLE rd=rc,icopy,iswap

rd=xswizzle(rc,icopy,iswap)

31 26	25 24	23 18	17 12	11 6	5 0
X.SWIZZLE	ih	rd	rc	icopya	iswapa
6	2	6	6	6	6

icopya ← $icopy_{5..0}$
iswapa ← $iswap_{5..0}$
ih ← $icopy_6$ || $iswap_6$

Fig. 47A

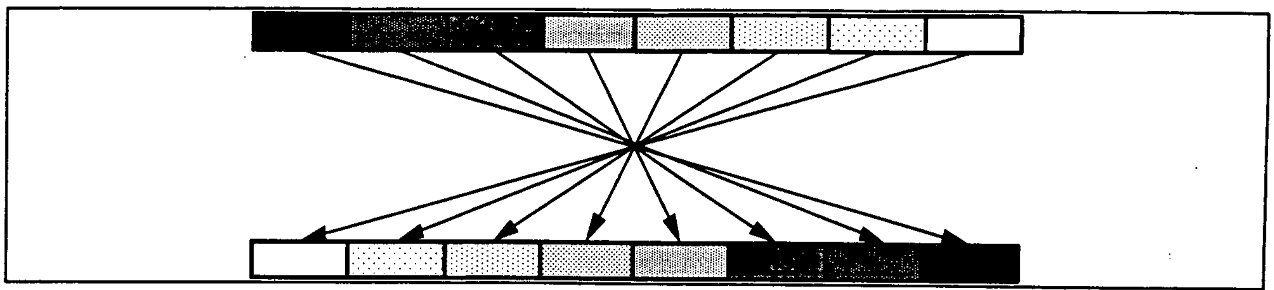
Definition

```
def GroupSwizzleImmediate(ih,rd,rc,icopya,iswapa) as
	icopy ← ih1 || icopya
	iswap ← ih0 || iswapa
	c ← RegRead(rc, 128)
	for i ← 0 to 127
		ai ← c(i & icopy) ^ iswap
	endfor
	RegWrite(rd, 128, a)
enddef
```

Exceptions

none

Fig. 47B



16-bit reverse

Fig. 47C

X.SELECT.8	Crossbar select bytes

Format

op ra=rd,rc,rb

ra=op(rd,rc,rb)

31 24	23 18	17 12	11 6	5 0
op	**rd**	**rc**	**rb**	**ra**
8	6	6	6	6

Fig. 47D

Definition

def CrossbarTernary(op,rd,rc,rb,ra) as
    d ← RegRead(rd, 128)
    c ← RegRead(rc, 128)
    b ← RegRead(rb, 128)
    dc ← d || c
    for i ← 0 to 15
        $j \leftarrow b_{8*i+4..8*i}$
        $a_{8*i+7..8*i} \leftarrow dc_{8*j+7..8*j}$
    endfor
    RegWrite(ra, 128, a)
enddef

Exceptions

none

Fig. 47E

Pin summary

A20M#	I	**Address bit 20 Mask** is an emulator signal.
A31..A3	IO	**Address**, in combination with **byte enable**, indicate the physical addresses of memory or device that is the target of a bus transaction. This signal is an output, when the processor is initiating the bus transaction, and an input when the processor is receiving an inquire transaction or snooping another processor's bus transaction.
ADS#	IO	**ADdress Strobe**, when asserted, indicates new bus transaction by the processor, with valid **address** and **byte enable** simultaneously driven.
ADSC#	O	**Address Strobe Copy** is driven identically to **address strobe**
AHOLD	I	**Address HOLD**, when asserted, causes the processor to cease driving **address** and **address parity** in the next bus clock cycle.
AP	IO	**Address Parity** contains even parity on the same cycle as **address**. **Address parity** is generated by the processor when **address** is an output, and is checked when **address** is an input. A parity error causes a bus error machine check.
APCHK#	O	**Address Parity CHecK** is asserted two bus clocks after EADS# if **address parity** is not even parity of **address**.
APICEN	I	**Advanced Programmable Interrupt Controller ENable** is not implemented.
BE7#..BE0#	IO	**Byte Enable** indicates which bytes are the subject of a read or write transaction and are driven on the same cycle as **address**.
BF1..BF0	I	**Bus Frequency** is sampled to permit software to select the ratio of the processor clock to the bus clock.
BOFF#	I	**BackOFF** is sampled on the rising edge of each bus clock, and when asserted, the processor floats bus signals on the next bus clock and aborts the current bus cycle, until the backoff signal is sampled negated.
BP3..BP0	O	**BreakPoint** is an emulator signal.
BRDY#	I	**Bus ReaDY** indicates that valid data is present on **data** on a read transaction, or that **data** has been accepted on a write transaction.
BRDYC#	I	**Bus ReaDY Copy** is identical to BRDY#; asserting either signal has the same effect.
BREQ	O	**Bus REQuest** indicates a processor initiated bus request.

Fig. 48

BUSCHK#	I	**BUS CHecK** is sampled on the rising edge of the bus clock, and when asserted, causes a bus error machine check.
CACHE#	O	**CACHE**, when asserted, indicates a cacheable read transaction or a burst write transaction.
CLK	I	bus **CLocK** provides the bus clock timing edge and the frequency reference for the processor clock.
CPUTYP	I	**CPU TYPe**, if low indicates the primary processor, if high, the dual processor.
D/C#	I	**Data/Code** is driven with the address signal to indicate data, code, or special cycles.
D63..D0	IO	**Data** communicates 64 bits of data per **bus clock**.
D/P#	O	**Dual/Primary** is driven (asserted, low) with **address** on the primary processor
DP7..DP0	IO	**Data Parity** contains even parity on the same cycle as **data**. A parity error causes a bus error machine check.
DPEN#	IO	**Dual Processing Enable** is asserted (driven low) by a Dual processor at reset and sampled by a Primary processor at the falling edge of reset.
EADS#	I	**External Address Strobe** indicates that an external device has driven **address** for an inquire cycle.
EWBE#	I	**External Write Buffer Empty** indicates that the external system has no pending write.
FERR#	O	**Floating point ERRor** is an emulator signal.
FLUSH#	I	**cache FLUSH** is an emulator signal.
FRCMC#	I	**Functional Redundancy Checking Master/Checker** is not implemented.
HIT#	IO	**HIT** indicates that an inquire cycle or cache snoop hits a valid line.
HITM#	IO	**HIT to a Modfied line** indicates that an inquire cycle or cache snoop hits a sub-block in the M cache state.
HLDA	O	**bus HoLD Acknowlege** is asserted (driven high) to acknowlege a **bus hold request**
HOLD	I	**bus HOLD request** causes the processor to float most of its pins and assert **bus hold acknowlege** after completing all outstanding bus transactions, or during reset.
IERR#	O	**Internal ERRor** is an emulator signal.
IGNNE#	I	**IGNore Numeric Error** is an emulator signal.
INIT	I	**INITialization** is an emulator signal.
INTR	I	**maskable INTeRrupt** is an emulator signal.
INV	I	**INValidation** controls whether to invalidate the addressed cache sub-block on an inqure transaction.

Fig. 48 (cont'd)

KEN#	I	**Cache ENable** is driven with **address** to indicate that the read or write transaction is cacheable.
LINT1..LINT0	I	**Local INTerrupt** is not implemented.
LOCK#	O	**bus LOCK** is driven starting with **address** and ending after **bus ready** to indicate a locked series of bus transactions.
M/IO#	O	**Memory/Input Output** is driven with **address** to indicate a memory or I/O transaction.
NA#	I	**Next Address** indicates that the external system will accept an **address** for a new bus cycle in two bus clocks.
NMI	I	**Non Maskable Interrupt** is an emulator signal.
PBGNT#	IO	**Private Bus GraNT** is driven between Primary and Dual processors to indicate that bus arbitration has completed, granting a new master access to the bus.
PBREQ#	IO	**Private Bus REQuest** is driven between Primary and Dual processors to request a new master access to the bus.
PCD	O	**Page Cache Disable** is driven with address to indicate a not cacheable transaction.
PCHK#	O	**Parity CHecK** is asserted (driven low) two bus clocks after **data** appears with odd parity on enabled bytes.
PHIT#	IO	**Private HIT** is driven between Primary and Dual processors to indicate that the current read or write transaction addresses a valid cache sub-block in the slave processor.
PHITM#	IO	**Private HIT Modified** is driven between Primary and Dual processors to indicate that the current read or write transaction addresses a modified cache sub-block in the slave processor.
PICCLK	I	**Programmable Interrupt Controller CLocK** is not implemented.
PICD1..PICD0	IO	**Programmable Interrupt Controller Data** is not implemented.
PEN#	I	**Parity Enable**, if active on the data cycle, allows a parity error to cause a bus error machine check.
PM1..PM0	O	**Performance Monitoring** is an emulator signal.
PRDY	O	**Probe ReaDY** is not implemented.
PWT	O	**Page Write Through** is driven with **address** to indicate a not write allocate transaction.
R/S#	I	**Run/Stop** is not implemented.
RESET	I	**RESET** causes a processor reset.
SCYC	O	**Split CYCle** is asserted during **bus lock** to indicate that more than two transactions are in the series of bus transactions.

Fig. 48 (c nt'd)

SMI#	I	**System Management Interrupt** is an emulator signal.
SMIACT#	O	**System Management Interrupt ACTive** is an emulator signal.
STPCLK#	I	**SToP CLocK** is an emulator signal.
TCK	I	**Test CLocK** follows IEEE 1149.1.
TDI	I	**Test Data Input** follows IEEE 1149.1.
TDO	O	**Test Data Output** follows IEEE 1149.1.
TMS	I	**Test Mode Select** follows IEEE 1149.1.
TRST#	I	**Test ReSeT** follows IEEE 1149.1.
VCC2	I	VCC of 2.8V at 25 pins
VCC3	I	VCC of 3.3V at 28 pins
VCC2DET#	O	VCC2 DETect sets appropriate VCC2 voltage level.
VSS	I	VSS supplied at 53 pins
W/R#	O	**Write/Read** is driven with address to indicate write vs. read transaction.
WB/WT#	I	**Write Back/Write Through** is returned to indicate that data is permitted to be cached as write back.

Fig. 48 (cont'd)

Electrical Specifications

Clock rate	66 MHz		75 MHz		100 MHz		133 MHz		
Parameter	min	max	min	max	min	max	min	max	unit
CLK frequency	33.3	66.7	37.5	75	50	100		133	MHz
CLK period	15.0	30.0	13.3	26.3	10.0	20.0			ns
CLK high time (≥2v)	4.0		4.0		3.0				ns
CLK low time (≤0.8V)	4.0		4.0		3.0				ns
CLK rise time (0.8V->2V)	0.15	1.5	0.15	1.5	0.15	1.5			ns
CLK fall time (2V->0.8V)	0.15	1.5	0.15	1.5	0.15	1.5			ns
CLK period stability		250		250		250			ps

Fig. 49A

A31..3 valid delay	1.1	6.3	1.1	4.5	1.1	4.0			ns
A31..3 float delay		10.0		7.0		7.0			ns
ADS# valid delay	1.0	6.0	1.0	4.5	1.0	4.0			ns
ADS# float delay		10.0		7.0		7.0			ns
ADSC# valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
ADSC# float delay		10.0		7.0		7.0			ns
AP valid delay	1.0	8.5	1.0	5.5	1.0	5.5			ns
AP float delay		10.0		7.0		7.0			ns
APCHK# valid delay	1.0	8.3	1.0	4.5	1.0	4.5			ns
BE7..0# valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
BE7..0# float delay		10.0		7.0		7.0			ns
BP3..0 valid delay	1.0	10.0							ns
BREQ valid delay	1.0	8.0	1.0	4.5	1.0	4.0			ns
CACHE# valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
CACHE# float delay		10.0		7.0		7.0			ns
D/C# valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
D/C# float delay		10.0		7.0		7.0			ns
D63..0 write data valid delay	1.3	7.5	1.3	4.5	1.3	4.5			ns
D63..0 write data float delay		10.0		7.0		7.0			ns
DP7..0 write data valid delay	1.3	7.5	1.3	4.5	1.3	4.5			ns
DP7..0 write data float delay		10.0		7.0		7.0			ns
FERR# valid delay	1.0	8.3	1.0	4.5	1.0	4.5			ns
HIT# valid delay	1.0	6.8	1.0	4.5	1.0	4.0			ns
HITM# valid delay	1.1	6.0	1.1	4.5	1.1	4.0			ns
HLDA valid delay	1.0	6.8	1.0	4.5	1.0	4.0			ns
IERR# valid delay	1.0	8.3							ns
LOCK# valid delay	1.1	7.0	1.1	4.5	1.1	4.0			ns
LOCK# float delay		10.0		7.0		7.0			ns
M/IO# valid delay	1.0	5.9	1.0	4.5	1.0	4.0			ns
M/IO# float delay		10.0		7.0		7.0			ns
PCD valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
PCD float delay		10.0		7.0		7.0			ns
PCHK# valid delay	1.0	7.0	1.0	4.5	1.0	4.5			ns
PM1..0 valid delay	1.0	10.0							ns
PRDY valid delay	1.0	8.0							ns
PWT valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
PWT float delay		10.0		7.0		7.0			ns
SCYC valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
SCYC float delay		10.0		7.0		7.0			ns
SMIACT# valid delay	1.0	7.3	1.0	4.5	1.0	4.0			ns
W/R# valid delay	1.0	7.0	1.0	4.5	1.0	4.0			ns
W/R# float delay		10.0		7.0		7.0			ns

Fig. 49B

A31..5 setup time	6.0		3.0		3.0			ns
A31..5 hold time	1.0		1.0		1.0			ns
A20M# setup time	5.0		3.0		3.0			ns
A20M# hold time	1.0		1.0		1.0			ns
AHOLD setup time	5.5		3.5		3.5			ns
AHOLD hold time	1.0		1.0		1.0			ns
AP setup time	5.0		1.7		1.7			ns
AP hold time	1.0		1.0		1.0			ns
BOFF# setup time	5.5		3.5		3.5			ns
BOFF# hold time	1.0		1.0		1.0			ns
BRDY# setup time	5.0		3.0		3.0			ns
BRDY# hold time	1.0		1.0		1.0			ns
BRDYC# setup time	5.0		3.0		3.0			ns
BRDYC# hold time	1.0		1.0		1.0			ns
BUSCHK# setup time	5.0		3.0		3.0			ns
BUSCHK# hold time	1.0		1.0		1.0			ns
D63..0 read data setup time	2.8		1.7		1.7			ns
D63..0 read data hold time	1.5		1.5		1.5			ns
DP7..0 read data setup time	2.8		1.7		1.7			ns
DP7..0 read data hold time	1.5		1.5		1.5			ns
EADS# setup time	5.0		3.0		3.0			ns
EADS# hold time	1.0		1.0		1.0			ns
EWBE# setup time	5.0		1.7		1.7			ns
EWBE# hold time	1.0		1.0		1.0			ns
FLUSH# setup time	5.0		1.7		1.7			ns
FLUSH# hold time	1.0		1.0		1.0			ns
FLUSH# async pulse width	2		2		2			CLK
HOLD setup time	5.0		1.7		1.7			ns
HOLD hold time	1.5		1.5		1.5			ns
IGNNE# setup time	5.0		1.7		1.7			ns
IGNNE# hold time	1.0		1.0		1.0			ns
IGNNE# async pulse width	2		2		2			CLK
INIT setup time	5.0		1.7		1.7			ns
INIT hold time	1.0		1.0		1.0			ns
INIT async pulse width	2		2		2			CLK
INTR setup time	5.0		1.7		1.7			ns
INTR hold time	1.0		1.0		1.0			ns
INV setup time	5.0		1.7		1.7			ns
INV hold time	1.0		1.0		1.0			ns
KEN# setup time	5.0		3.0		3.0			ns
KEN# hold time	1.0		1.0		1.0			ns
NA# setup time	4.5		1.7		1.7			ns

Fig. 49C

NA# hold time	1.0		1.0		1.0			ns
NMI setup time	5.0		1.7		1.7			ns
NMI hold time	1.0		1.0		1.0			ns
NMI async pulse width	2		2		2			CLK
PEN# setup time	4.8		1.7		1.7			ns
PEN# hold time	1.0		1.0		1.0			ns
R/S# setup time	5.0		1.7		1.7			ns
R/S# hold time	1.0		1.0		1.0			ns
R/S# async pulse width	2		2		2			CLK
SMI# setup time	5.0		1.7		1.7			ns
SMI# hold time	1.0		1.0		1.0			ns
SMI# async pulse width	2		2		2			CLK
STPCLK# setup time	5.0		1.7		1.7			ns
STPCLK# hold time	1.0		1.0		1.0			ns
WB/WT# setup time	4.5		1.7		1.7			ns
WB/WT# hold time	1.0		1.0		1.0			ns

Fig. 49C (cont'd)

RESET setup time	5.0		1.7		1.7			ns
RESET hold time	1.0		1.0		1.0			ns
RESET pulse width	15		15		15			CLK
RESET active	1.0		1.0		1.0			ms
BF2..0 setup time	1.0		1.0		1.0			ms
BF2..0 hold time	2		2		2			CLK
BRDYC# hold time	1.0		1.0		1.0			ns
BRDYC# setup time	2		2		2			CLK
BRDYC# hold time	2		2		2			CLK
FLUSH# setup time	5.0		1.7		1.7			ns
FLUSH# hold time	1.0		1.0		1.0			ns
FLUSH# setup time	2		2		2			CLK
FLUSH# hold time	2		2		2			CLK

Fig. 49D

PBREQ# flight time	0	2.0							ns
PBGNT# flight time	0	2.0							ns
PHIT# flight time	0	2.0							ns
PHITM# flight time	0	1.8							ns
A31..5 setup time	3.7								ns
A31..5 hold time	0.8								ns
D/C# setup time	4.0								ns
D/C# hold time	0.8								ns
W/R# setup time	4.0								ns
W/R# hold time	0.8								ns
CACHE# setup time	4.0								ns
CACHE# hold time	1.0								ns
LOCK# setup time	4.0								ns
LOCK# hold time	0.8								ns
SCYC setup time	4.0								ns
SCYC hold time	0.8								ns
ADS# setup time	5.8								ns
ADS# hold time	0.8								ns
M/IO# setup time	5.8								ns
M/IO# hold time	0.8								ns
HIT# setup time	6.0								ns
HIT# hold time	1.0								ns
HITM# setup time	6.0								ns
HITM# hold time	0.7								ns
HLDA setup time	6.0								ns
HLDA hold time	0.8								ns
DPEN# valid time		10.0							CLK
DPEN# hold time	2.0								CLK
D/P# valid delay (primary)	1.0	8.0							ns

Fig. 49E

TCK frequency		25				25			MHz
TCK period	40.0				40.0				ns
TCK high time (≥2v)	14.0				14.0				ns
TCK low time (≤0.8V)	14.0				14.0				ns
TCK rise time (0.8V->2V)		5.0				5.0			ns
TCK fall time (2V->0.8V)		5.0				5.0			ns
TRST# pulse width	30.0				30.0				ns

Fig. 49F

TDI setup time	5.0				5.0				ns
TDI hold time	9.0				9.0				ns
TMS setup time	5.0				5.0				ns
TMS hold time	9.0				9.0				ns
TDO valid delay	3.0	13.0			3.0	13.0			ns
TDO float delay		16.0				16.0			ns
all outputs valid delay	3.0	13.0			3.0	13.0			ns
all outputs float delay		16.0				16.0			ns
all inputs setup time	5.0				5.0				ns
all inputs hold time	9.0				9.0				ns

Fig. 49G

Operation codes

L.8	Load signed byte
L.16.B	Load signed doublet big-endian
L.16.A.B	Load signed doublet aligned big-endian
L.16.L	Load signed doublet little-endian
L.16.A.L	Load signed doublet aligned little-endian
L.32.B	Load signed quadlet big-endian
L.32.A.B	Load signed quadlet aligned big-endian
L.32.L	Load signed quadlet little-endian
L.32.A.L	Load signed quadlet aligned little-endian
L.64.B	Load signed octlet big-endian
L.64.A.B	Load signed octlet aligned big-endian
L.64.L	Load signed octlet little-endian
L.64.A.L	Load signed octlet aligned little-endian
L.128.B	Load hexlet big-endian
L.128.A.B	Load hexlet aligned big-endian
L.128.L	Load hexlet little-endian
L.128.A.L	Load hexlet aligned little-endian
L.U.8	Load unsigned byte
L.U.16.B	Load unsigned doublet big-endian
L.U.16.A.B	Load unsigned doublet aligned big-endian
L.U.16.L	Load unsigned doublet little-endian
L.U.16.A.L	Load unsigned doublet aligned little-endian
L.U.32.B	Load unsigned quadlet big-endian
L.U.32.A.B	Load unsigned quadlet aligned big-endian
L.U.32.L	Load unsigned quadlet little-endian
L.U.32.A.L	Load unsigned quadlet aligned little-endian
L.U.64.B	Load unsigned octlet big-endian
L.U.64.A.B	Load unsigned octlet aligned big-endian
L.U.64.L	Load unsigned octlet little-endian
L.U.64.A.L	Load unsigned octlet aligned little-endian

Fig. 50A

Selection

number format	type	size	alignment	ordering
signed byte		8		
unsigned byte	U	8		
signed integer		16 32 64		L B
signed integer aligned		16 32 64	A	L B
unsigned integer	U	16 32 64		L B
unsigned integer aligned	U	16 32 64	A	L B
register		128		L B
register aligned		128	A	L B

Format

op rd=rc,rb

rd=op(rc,rb)

31 24	23 18	17 12	11 6	5 0
L.MINOR	**rd**	**rc**	**rb**	**op**
8	6	6	6	6

Fig. 50B

Definition

```
def Load(op,rd,rc,rb) as
    case op of
        L16L, L32L, L8, L16AL, L32AL, L16B, L32B, L16AB, L32AB,
        L64L, L64AL, L64B, L64AB:
            signed ← true
        LU16L, LU32L, LU8, LU16AL, LU32AL, LU16B, LU32B, LU16AB, LU32AB,
        LU64L, LU64AL, LU64B, LU64AB:
            signed ← false
        L128L, L128AL, L128B, L128AB:
            signed ← undefined
    endcase
    case op of
        L8, LU8:
            size ← 8
        L16L, LU16L, L16AL, LU16AL, L16B, LU16B, L16AB, LU16AB:
            size ← 16
        L32L, LU32L, L32AL, LU32AL, L32B, LU32B, L32AB, LU32AB:
            size ← 32
        L64L, LU64L, L64AL, LU64AL, L64B, LU64B, L64AB, LU64AB:
            size ← 64
        L128L, L128AL, L128B, L128AB:
            size ← 128
    endcase
    lsize ← log(size)
    case op of
        L16L, LU16L, L32L, LU32L, L64L, LU64L, L128L,
        L16AL, LU16AL, L32AL, LU32AL, L64AL, LU64AL, L128AL:
            order ← L
        L16B, LU16B, L32B, LU32B, L64B, LU64B, L128B,
        L16AB, LU16AB, L32AB, LU32AB, L64AB, LU64AB, L128AB:
            order ← B
        L8, LU8:
            order ← undefined
    endcase
```

Fig. 50C

```
    c ← RegRead(rc, 64)
    b ← RegRead(rb, 64)
    VirtAddr ← c + (b66-lsize..0 || 0^(lsize-3))
    case op of
        L16AL, LU16AL, L32AL, LU32AL, L64AL, LU64AL, L128AL,
        L16AB, LU16AB, L32AB, LU32AB, L64AB, LU64AB, L128AB:
            if (clsize-4..0 ≠ 0 then
                raise AccessDisallowedByVirtualAddress
            endif
        L16L, LU16L, L32L, LU32L, L64L, LU64L, L128L,
        L16B, LU16B, L32B, LU32B, L64B, LU64B, L128B:
        L8, LU8:
    endcase
    m ← LoadMemory(c,VirtAddr,size,order)
    a ← (msize-1 and signed)^(128-size) || m
    RegWrite(rd, 128, a)
enddef
```

Exceptions

Access disallowed by virtual address
Access disallowed by tag
Access disallowed by global TB
Access disallowed by local TB
Access detail required by tag
Access detail required by local TB
Access detail required by global TB
Local TB miss
Global TB miss

Fig. 50C (cont)

Operation codes

L.I.8	Load immediate signed byte
L.I.16.A.B	Load immediate signed doublet aligned big-endian
L.I.16.B	Load immediate signed doublet big-endian
L.I.16.A.L	Load immediate signed doublet aligned little-endian
L.I.16.L	Load immediate signed doublet little-endian
L.I.32.A.B	Load immediate signed quadlet aligned big-endian
L.I.32.B	Load immediate signed quadlet big-endian
L.I.32.A.L	Load immediate signed quadlet aligned little-endian
L.I.32.L	Load immediate signed quadlet little-endian
L.I.64.A.B	Load immediate signed octlet aligned big-endian
L.I.64.B	Load immediate signed octlet big-endian
L.I.64.A.L	Load immediate signed octlet aligned little-endian
L.I.64.L	Load immediate signed octlet little-endian
L.I.128.A.B	Load immediate hexlet aligned big-endian
L.I.128.B	Load immediate hexlet big-endian
L.I.128.A.L	Load immediate hexlet aligned little-endian
L.I.128.L	Load immediate hexlet little-endian
L.I.U.8	Load immediate unsigned byte
L.I.U.16.A.B	Load immediate unsigned doublet aligned big-endian
L.I.U.16.B	Load immediate unsigned doublet big-endian
L.I.U.16.A.L	Load immediate unsigned doublet aligned little-endian
L.I.U.16.L	Load immediate unsigned doublet little-endian
L.I.U.32.A.B	Load immediate unsigned quadlet aligned big-endian
L.I.U.32.B	Load immediate unsigned quadlet big-endian
L.I.U.32.A.L	Load immediate unsigned quadlet aligned little-endian
L.I.U.32.L	Load immediate unsigned quadlet little-endian
L.I.U.64.A.B	Load immediate unsigned octlet aligned big-endian
L.I.U.64.B	Load immediate unsigned octlet big-endian
L.I.U.64.A.L	Load immediate unsigned octlet aligned little-endian
L.I.U.64.L	Load immediate unsigned octlet little-endian

Fig. 51A

Selection

number format	type	size	alignment	ordering
signed byte		8		
unsigned byte	U	8		
signed integer		16 32 64		L B
signed integer aligned		16 32 64	A	L B
unsigned integer	U	16 32 64		L B
unsigned integer aligned	U	16 32 64	A	L B
register		128		L B
register aligned		128	A	L B

Format

op rd=rc,offset

rd=op(rc,offset)

31 24	23 18	17 12	11 0
op	**rd**	**rc**	**offset**
8	6	6	12

Fig. 51B